

**ASSESSMENT OF AIRCRAFT DEICING FLUID MANAGEMENT OPTIONS
FOR AIR FORCE BASES**

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Abstract

Assessment of Aircraft Deicing Fluid Management Options for Air Force Bases

by

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The United States Air Force Center For Environmental Excellence (AFCEE) requested an analysis of aircraft deicing fluid (ADF) management options available for the treatment and disposal of ADF contaminated stormwater. AFCEE's concern stems from growing national restrictions on stormwater runoff. The restrictions force the Air Force to invest in containment and treatment systems to manage ADF contaminated stormwater. Therefore, several airplane deicing fluid storage and treatment options were evaluated. This departmental report evaluates two different storage options, including on and off-line storage, and three different ADF treatment options, including aerobic treatment, anaerobic treatment, and recycling.

The critical issue was finding a way to store the ADF contaminated runoff and dispose of the collected waste in order to ensure that flight operations will not be restricted. In order to evaluate the effectiveness of deicing treatment options, many criteria were considered. Meeting EPA regulations coupled with a minimum cost

solution were the major criteria. Other criteria included meeting National Pollutant Discharge Elimination System Permit requirements and management and maintenance requirements.

After careful analysis of the treatment options, the following conclusions can be made. The implementation of a flow attenuation facility with the controlled discharge to a WWTP or POTW appears to be the most effective management option based on the criteria for ADF contaminated stormwater. In terms of cost, the aerobic option appears to be the most cost feasible, with annual costs of about \$51,000 to treat 300,000 gallons of ADF contaminated stormwater at an Air Force base. This cost includes capital, operations and maintenance costs assuming a twenty year operating life. With properly designed equalization basins and subsequent discharge to a POTW or WWTP, it is possible for an Air Force Base to consistently meet regulation requirements along with performance requirements. Additional management and maintenance at the POTW or WWTP will be necessary due the increased stress placed on the POTW by the contaminated stormwater. This additional cost is included in the annual cost number cited above.

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1.0 INTRODUCTION

1.1 BACKGROUND

The management of aircraft deicing and anti-icing fluid presents a challenge for many airports and military installations. Because the safety of passengers is the Federal Aviation Administration's (FAA) number one priority, large quantities of Aircraft Deicing Fluid (ADF) are applied to aircraft to ensure the aircraft's safety. Of the ADF applied, only 16% remains on the aircraft surfaces (Transport Canada 1988). Typically, 80% of the fluid used is deposited on the ground due to spray drift, jet blast, and wind shearing during taxi and takeoff (MacDonald et al., 1992, Mayer et al., 1986, Hartwell 1976). Because of the environmental impact of ADF usage, many Air Force aircraft often do not fly during snow, rain, and ice storms. The grounding of aircraft is not due to safety concerns but rather environmental concerns. For example, Westover Air Base, home of multiple aircraft, is surrounded by wetlands. In order to avoid notices of violation due to deicing fluid runoff, the large aircraft do not fly in icy conditions. Therefore, sortie generation is low in winter months, the late aircraft rate increases, and mission completion becomes extremely difficult. This is not acceptable in order to maintain flight readiness. Finding a way to store ADF contaminated runoff, treat, and dispose of the collected waste in order to ensure that the flight operations will not be restricted is critical.

1.2 PURPOSE AND SCOPE

The Air Force Center For Environmental Excellence (AFCEE) has requested an analysis of the management alternatives that are available for the storage and treatment of spent ADF. AFCEE's concern stems from growing restrictions on stormwater runoff. This departmental report evaluates the storage, treatment, and disposal options for spent ADF in order to determine the best management option for Air Force flight operations. Figure 1 shows the elements of a typical airport deicing and stormwater system and the opportunities for control within the system.

Airport deicing systems may be represented by four major components:

- ADF application
- Stormwater collection
- Stormwater storage
- Stormwater treatment, recycling, and disposal

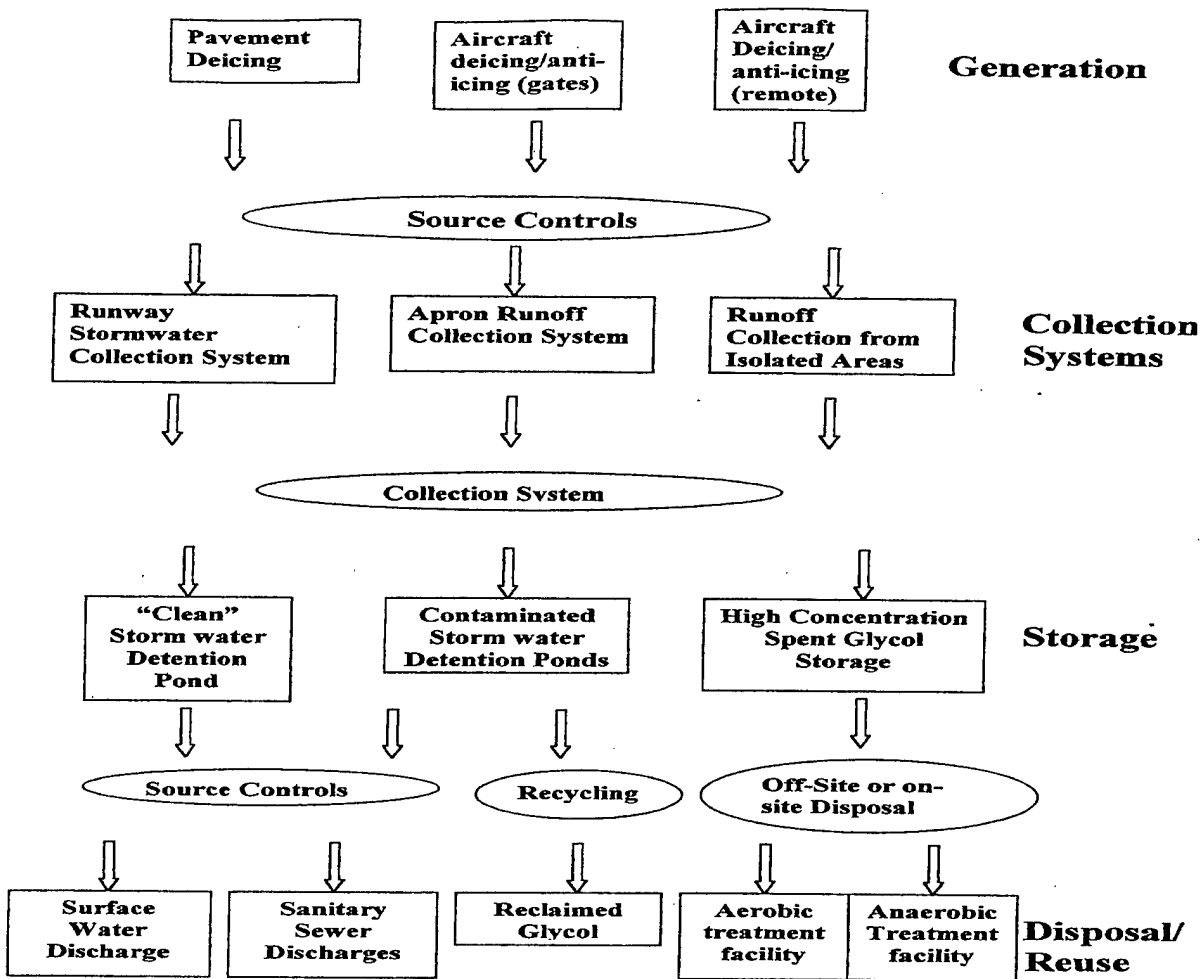


Figure 1: Elements of a Typical Airport Deicing and Stormwater System, and Opportunities for Control Between System Levels.

Source: Wagoner 1994

This report evaluates the last two components; stormwater storage and stormwater treatment, recycling, and disposal. For each component, various alternatives were investigated. These alternatives include the following:

- Storm water Storage
 - On-line storage
 - Off-line storage
 - Detention Ponds

- Retention Ponds
 - Aerobic Ponds
- Storm water treatment, recycling, and disposal
 - On-site aerobic facility
 - Off-site aerobic facility
 - On-site anaerobic facility
 - Recycling

To evaluate the effectiveness of storm water storage, treatment, recycling, and disposal options, it was important to consider many criteria. Meeting EPA regulations coupled with a minimum cost solution was the number one concern. The following criteria were evaluated in order to determine the best management option.

- Cost: This report evaluates both capital costs and operation and maintenance costs of the equipment use.
- Performance: This report evaluates the percent of glycol removed from the waste stream.
- NPDES regulation: Dischargers must meet the National Pollutant Discharge Elimination standards in order to obtain permitting for the discharge.
- Management/ Maintenance: Due to manpower concerns, the operability and ease of the ADF treatment system was analyzed.

1.3 LIMITATIONS

This departmental report only deals with the collected ADF. After falling on the ground, ADF typically has three possible routes to follow. ADF can immediately become part of the surface water runoff, it can be retained in snow pile deposits around the airfield until melting/ runoff occurs, or it can be collected through various source control options (MacDonald 1992). Typically, 30% of the ADF is stored in snow piles and released when the snow melts (Transport Canada 1988). Potentially, approximately 60% of the spent ADF can be collected (Transport Canada 1988). This report deals with the treatment, storage and disposal of the collected ADF, not the ADF lost to storm water runoff or snow pile deposits.

1.4 METHODOLOGY

First, aircraft deicing fluid composition, companies that manufacture ADF, regulations that apply to deicing fluid, and the specific concerns of the Air Force were researched. This information was found by contacting companies such as Union Carbide and Lyondell Chemicals. Personnel familiar with deicing operations at various air bases around the country were also contacted. Specific companies that manufacturer wastewater treatment systems and case studies of current deicing operating procedures at Air Force bases and commercial airports were identified. Specific companies included EFX Inc, Waste Stream Environmental Inc., Glycol Specialists, AnAerobics Inc., and InfraTek.

1.5 STRUCTURE OF REPORT

Following the introduction section, this report is divided into five main sections. The first section, deicing and anti-icing overview, discusses deicing processes and ADF usage. The subsection entitled Aircraft Deicing Fluids discusses propylene and ethylene glycol toxicity, while the Clean Aircraft Concept section explains the Federal Aviation stance on deicing. The next subsection on generation, collection, storage, and treatment, reuse and disposal discusses the alternatives for each process and when and where they are used. For example, in the treatment, reuse and disposal section, each subsection (aerobic, anaerobic, recycling) gives a brief overview of the treatment process and how it works.

The second section discusses the criteria used to evaluate the treatment options. The third section, the evaluation of treatment options, is organized according to criteria. For example, cost of all four treatment options is discussed first. Then, the performance of all four treatment options is discussed, followed by the discussion of other pertinent points. Conclusions are provided in the fourth section that highlights the main points of the evaluation. The final section contains the recommendations of the most effective ADF treatment option that meets the needs of the Air Force.

2.0 DEICING AND ANTI-ICING OVERVIEW

Aircraft deicing entails removing ice and snow from an aircraft. This operation is usually performed while the aircraft is still on the parking ramp. Deicing is used to remove accumulated frozen deposits prior to taxiing as seen in Figure 2.

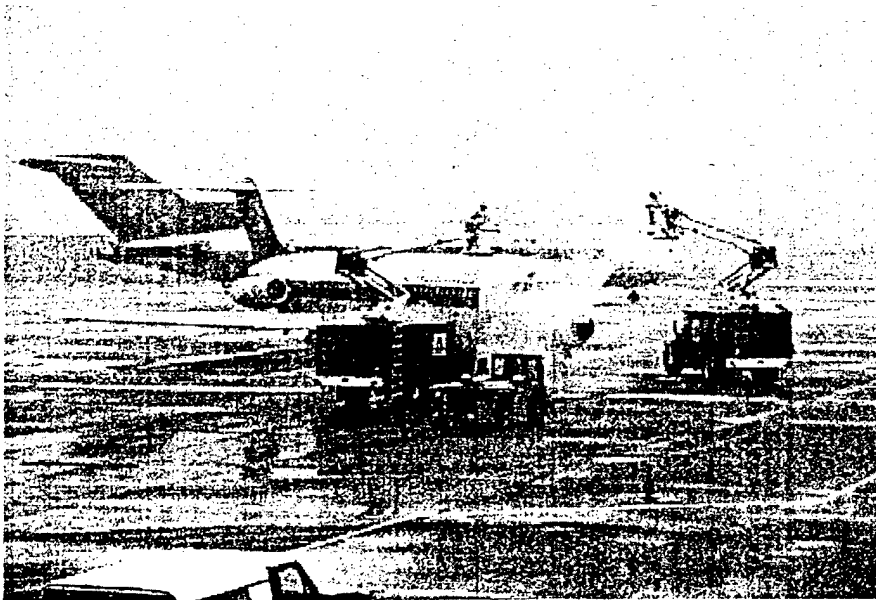


Figure 2: Deicing Operation Prior to Taxiing
Source: Northwest Airlines 2000

Anti-icing is performed whenever an aircraft may encounter icing conditions during take-off. This procedure is performed as close to departure as possible, allowing the maximum amount of anti-icing protection possible.

3.0 AIRCRAFT DEICING FLUID

The ratio of ADF concentrate to water typically ranges from 50:50 to 10:90 before application on the aircraft (Safferman et al. 1998). The ratio is a function of weather conditions and snow and ice accumulation. ADF concentrate is mainly glycol, specifically propylene and or ethylene glycol. The Air Force uses a propylene glycol mixture that is typically composed of 88% propylene glycol (PG), 0.5-0.6% 4(5)-methylbenzotriazole (MeBT), 1-2% proprietary additives (corrosion inhibitors, buffer, and surfactants), and water (Shieh et al. 1998).

MEBT is commonly used to inhibit metal corrosion. It is added to ADF to reduce the flammability hazard created from the corrosion reaction that occurs when glycol solutions come into contact with metal components carrying direct current (Downs 1968). Chronic ecological toxicity data for MeBT is not available although acute toxicity data indicates that MeBT is moderately toxic to *Lepomis macrochirus* (96 hour LC_{50} = 31 mg/L) and *Daphnia magna* (48 hour LC_{50} = 74 mg/L) (PMC 1996). MEBT is hydrophobic and has a potential recalcitrance to biodegradation. Therefore, it may build up in the subsurface or in sediments, an important consideration when thinking about the land treatment of ADF contaminated storm water (Cornell 2000).

There are two types of ADF: Type Type I and II. Type I is a relatively thin liquid used in deicing while Type II is a more viscous material that is typically used for anti-icing (Mericas and Wagoner 1994).

Under the guidance of Section 402 of the Clean Water Act, the FAA approves the use of ethylene glycol and propylene glycol as aircraft deicers (US EPA 1999). Propylene glycol is the main deicing chemical used by the Air Force. The Federal Drug Administration (FDA) classifies propylene glycol as a Generally Recognized as Safe (GRAS) additive (US Dept of Health 1993). Propylene glycol acts as an emulsifying agent, surfactant, and solvent in cosmetics, medicines, and food products. A summary of the LD₅₀ values for propylene glycol can be seen in Table 1 below.

Table 1 : LD₅₀ Data for Propylene Glycol
Source: EA Engineering, Science, and Technology 1994

Species	Propylene glycol (g/kg)	Reference
Rats	22-33.5	Laug et al., 1939, and Weatherby and Haag, 1938
Rabbits	15.7-19.2	Cavender and Sowinski, 1994
Guinea pigs	18.35-19.6	Smyth et al., 1941, and Laug et al., 1939
Mice	24.8-31.8	Laug et al., 1939, and Cavender and Sowinski, 1994
Dogs	10-20	Cavender and Sowinski, 1994

Due to Air Force regulation, propylene glycol is used as the Air Force's primary deicing agent over its cheaper and more toxic alternative, ethylene glycol. Although propylene glycol is a common chemical, it can cause detrimental effects to the environment when released in large quantities. The most common impacts on stormwater are measured in terms of changes in the concentration of a certain

chemical or physical constituents. ADF runoff exerts an extremely high biological oxygen demand (BOD) on receiving water if it is discharged without treatment. A high BOD results in dissolved oxygen depletion (Moffa 1996). Diluted propylene glycol, in other words, deicing fluid runoff at 1% deicing solution, has a Biological Oxygen Demand (BOD₅) of approximately 10,000 mg/L (Sills and Blakeslee 1992). In comparison, untreated domestic sewage has a BOD₅ of approximately 200 mg/L. This shows that propylene glycol can drastically affect the dissolved oxygen levels in a water body. Likewise, when discharged to a municipal wastewater treatment plant without prior treatment, ADF can stress the plant's aerobic treatment system, resulting in POTW discharge violations.

Ethylene glycol is a common product of antifreeze and deicing fluid. Unlike propylene glycol, ethylene glycol is subject to hazardous substance regulation (PROACT 1998). It is highly water-soluble and exerts a high biochemical oxygen demand on receiving waters. Ethylene glycol is toxic to aquatic and mammalian organisms, even at low concentrations (PROACT 1998). Acute effects of human exposure to ethylene glycol by ingestion include central nervous system depression, cardiopulmonary effects and later renal damage (US EPA 1999). Acute animal tests, such as LC₅₀ and LD₅₀ tests in rats, mice, and rabbits demonstrate that ethylene glycol has a moderate acute toxicity by inhalation or dermal exposure and low to moderate acute toxicity by ingestion. Chronic, noncancerous effects of ethylene glycol include kidney and liver damage (US EPA 1999). The EPA has not

established a reference concentration for ethylene glycol although the reference dose is 2.0 mg/kg/d (US EPA 1999). In other words, the EPA estimates that the consumption of this dose over a 70 year average lifetime would not likely result in chronic effects. No information is available on the reproductive or carcinogenic effects of ethylene glycol in humans. Ethylene glycol is a hazardous air pollutant under the Clean Air Act and is categorized as a hazardous substance under the Comprehensive Environmental, Response, Compensation, and Liability Act (CERCLA) (PROACT 1998). The use of ethylene glycol is subject to storage and release reporting requirements under the Emergency Planning and Community Right-To-Know Act (EPCRA) (PROACT 1998).

4.0 THE CLEAN AIRCRAFT CONCEPT

The Federal Aviation Administration (FAA) prohibits aircraft takeoff when “frost, ice, or snow adheres to airplane wings, propellers, or control surfaces” (Kotker 1999). This prohibition is called the Clean Airplane Concept. In addition, the FAA prohibits takeoff any time frost, ice or snow can “reasonably be expected to adhere to the airplane,” unless holdover timetables are employed (Kotker 1999). Holdover time is the time from when deicing or anti-icing fluid is applied and when it begins to fail. It is a function of ambient temperature, precipitation, and ADF type and mixture strength (Mericas and Wagoner 1994). Generally, the holdover time decreases with decreasing temperature. The lower the temperature, the more glycol

that needs to be applied to the aircraft. The FAA suggests aircraft personnel use the following factors in the listed order of priority when making an ADF application decision:

1. Safety of the crew and passengers
2. Risk of damaging or destroying the aircraft
3. Availability of the various fluids
4. Environmental impact
5. Cost (FAA, 1996)

5.0 OVERVIEW OF THE DEICING PROCESS

The deicing concept consists of four major components: generation, collection, storage, and disposal/reuse. Figure 1 showed the elements of a typical airport deicing and stormwater system and the various opportunities for control between system levels. The following sections discuss each component of the deicing management system in detail.

6.0 GENERATION

As a result of the March 1992 crash of USAir Flight 405 at La Guardia Airport in New York, a deicing related accident, more deicing fluid is used today than ever before (FAA 1999). Because of the consequences of any accident as a result of deicing practices, airlines and pilots tend to lean on the side of safety when deciding how much ADF to use. As a result, a general concept of "more equals better" has been employed. It is expected that 11×10^6 gallons of ADF were used at the 20 largest airports in North America during the 1992-1993 season (Mericas and Wagoner 1994). ADF use ranges from approximately 25,000 gal/yr for a small military base to 1.5 million gal/yr for a commercial airport (Strong -Gunderson et al.1998). Table 2 shows different estimates of how much deicing fluid is used per aircraft. Air Force Instruction 32-1002 states that anti-icing requires applying liquid deicing chemicals at a rate of 0.3 gallons per 1,000 square feet. Deicing requires "up to five times the quantity of chemical as anti-icing" (AFI 1994). Based on the data of ADF use per aircraft, this report assumes an average ADF use of 250 gal/aircraft. This can be seen in Figure 3.

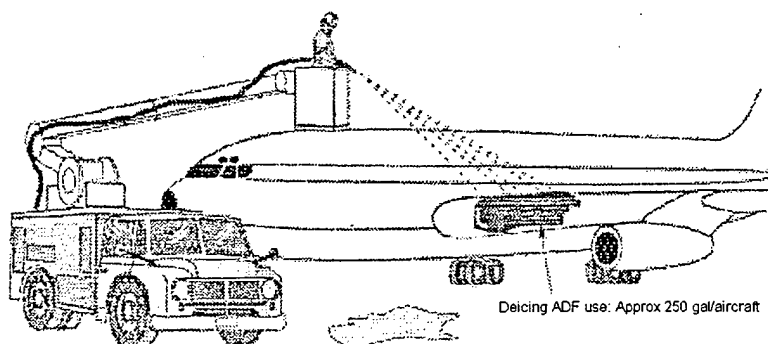


Figure 3: Typical Aircraft Deicing Operation and ADF Usage
Source: Westmark 2000

Table 2: ADF Use Per Aircraft for Deicing and Anti-icing Operations Combined

ADF use per aircraft for deicing and anti-icing operations (gal/aircraft)	Source of Information
1000	Mericas and Wagoner 1994
250	Westmark 2000
100	Conetta and Bracchitta et al. 1997
300	Evans 1996

7.0 COLLECTION SYSTEMS

There are many options for intercepting glycol-contaminated runoff. These include altering existing storm sewer networks, providing a flow diversion structure, using vacuum trucks, or creating deicing areas known as deicing pads.

7.1 STORMWATER SEWER NETWORKS

One strategy for intercepting glycol-contaminated runoff is to alter existing storm sewer networks to divert contaminated flows away from surface water discharges. Sewers can be diverted using blocks or valves and by constructing new lines to direct contaminated runoff from the deicing area to the storage system or sewer system (Mericas and Wagoner 1994). Control practices that can be applied to the drainage system are limited, especially for existing systems.

7.2 FLOW DIVERSION STRUCTURES

Flow diversion structures (gutters, drains, sewers, dikes, berms, swales, and graded pavement) are used to collect and divert runoff to divert the contamination of storm water and receiving water (US EPA 1999). A typical diversion swale can be seen in Figure 4. One of the most common methods for diverting flow is through storm water conveyance systems. Flow diversion structures are often modified by incorporating them into other pollution control Best Management Practices (BMPs). For example, diverted flow can be fed into an infiltration system, an infiltration basin

or a treatment facility (US EPA 1999). Advantages of using storm water diversion structures include low system maintenance requirements, low construction requirements, and directing contaminated storm water around noncontaminated storm water and vice versa (US EPA 1999). Disadvantages include erosion problems due to concentrated flows, potential groundwater contamination if conveyance channels have high infiltration capacities, inadequately treated discharges to undersized water treatment facilities, space limitation, cost, and high maintenance during heavy rains.

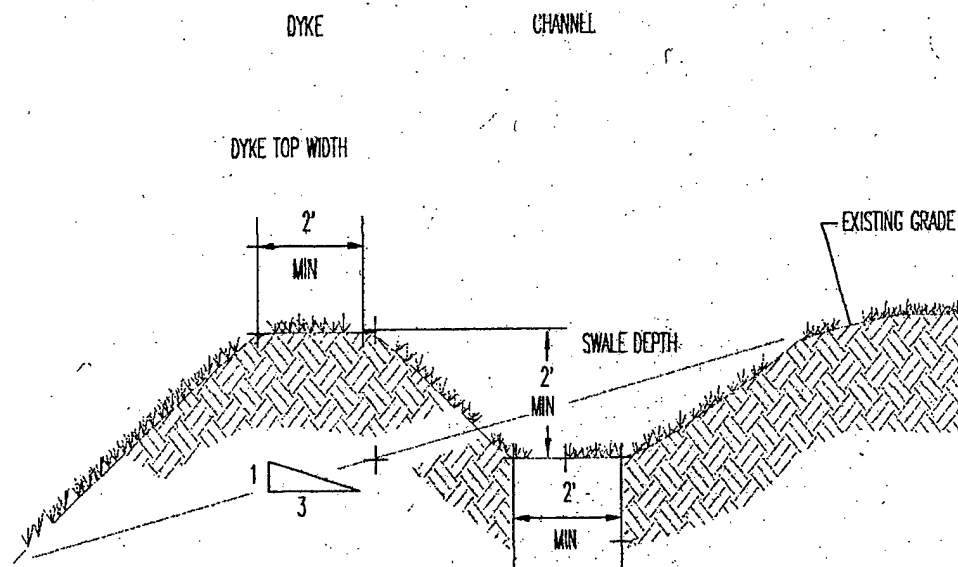


Figure 4: Typical Diversion Swale Details
Source: US EPA 1999

Drainage swales are not effective for the attenuation of pollution in snowmelt (Smith et al.1994). Because soil with initially high moisture content loses most or all of its infiltration capacity when frozen, infiltration should not be practiced in areas where the surrounding water bodies or aquifers could be affected by snowmelt (Smith et al.1994). This makes it difficult to employ drainage swales in areas where deicing occurs. Although, properly designed stormwater diversion systems are very effective for preventing stormwater from being contaminated and for routing contaminated flows to a proper treatment facility. For example, at Denver International Airport, flow diversion techniques intercept 80 percent of the glycol used in deicing activities and prevent it from entering the local receiving water body (Backer et al. 1994).

7.3 VACUUM TRUCKS

Vacuum trucks are modified street sweepers, which are capable of recovering deicing fluids, but are primarily designed to capture particulate matter. According to Lt Col Clune, Niagara Falls Air National Guard Base, modifications to a vacuum truck so that it can pick up liquids can be done but is not very effective (ProAct 1998). A typical vacuum truck can be seen in Figure 5.

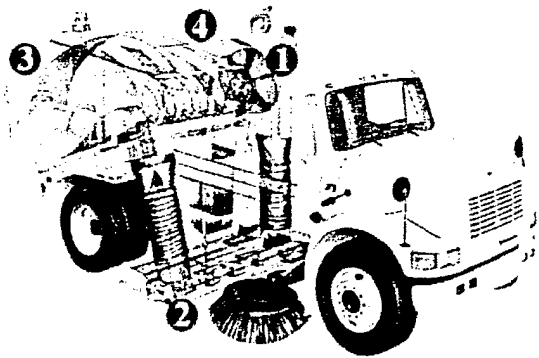


Figure 5: Vacuum Truck Used to Collect Spent ADF
Source: Tymco Inc 2000

7.4 DEICING PADS

Aviation Environmental Incorporated manufactures a deicing capture system. This system consists of a ground-cover pad with a chemical and sun-resistant polypropylene line, a foam berm, and aluminum batten bar fastening system (PROACT 1996). The containment platform is 30 by 50 feet. Used fluids are evacuated from the containment area using an 18 horsepower evacuation pump (PROACT 1996). The effluent is contained in holding tanks pending disposal.

Denver International Airport deicing is available at three deicing pads (Backer et al. 1994). The pads accommodate as many as five or six aircraft each. The deicing fluid collected in the deicing pad area is piped into storage tanks for recycling. The deicing pads can be seen in Figure 6. All storm water management at the airport is based on efforts to maintain separation of different water qualities, and to minimize collected volumes of “clean” water and to maximize the concentrations of collected contaminated water (Backer et al. 1994). The highly glycol-

concentrated water is reused. The water with low concentrations of ADF is treated locally.

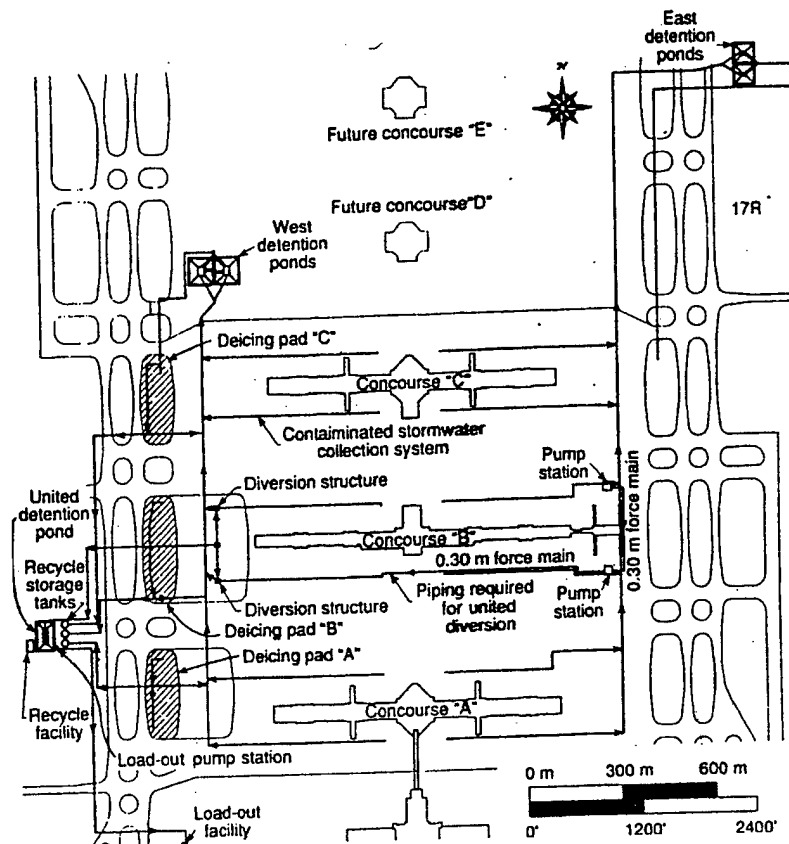


Figure 6: Deicing Pads at Denver International Airport
Source: Backer et al. 1994

8.0 STORMWATER STORAGE SYSTEMS

This section describes the differences between in-line and off-line storage. Although various in-line and off-line alternatives are discussed, the evaluation section will only compare in-line versus off-line storage, not the various options.

8.1 IN-LINE STORAGE

In-line storage is the use of the unused volume in the drainage system network of pipes and channels to store stormwater runoff (Moffa 1996). In-line storage is used to restrict flow, causing backup and storage in the drainage system. In-line storage capacity can also be provided by storage tank, basins, or surface ponds, which are connected in-line to the drainage network (Moffa 1996).

The degree to which the existing drainage system can be used for storage is a function of the pipe sizes, the pipe gradient (flat pipes are likely to provide the most storage capacity without susceptibility to folding in low areas), and the location for installation of control devices like weirs (Moffa 1996). There are two categories of in-line storage, fixed or adjustable. The following is a list of fixed and adjustable regulators (Moffa 1996).

Fixed Regulators

Orifices

Weirs

Steinscrew

Adjustable Regulators

Inflatable dams

Tilting plate regulators

Reverse-tainter gates

Hydrobrake	Float-controlled gates
Wirbeldrossel	Motor-operated or hydraulic gates
Swirl	
Stilling-pond weir	

Fixed systems are usually cheaper and require less maintenance but do not offer the flexibility to maximize the storage potential. Adjustable systems have the advantage of being connected to a real-time control (RTC) system, which, by a system of rainfall measurements, monitor the storm water levels in critical sections of the drainage system. This information is then used to hold back or release the storm water.

8.2 OFF-LINE STORAGE

Off-line storage is storage that is not in-line to the drainage system (Moffa 1996). Storage is achieved by diverting flow from the drainage system when a certain flow rate is exceeded (Moffa 1996). The stormwater is stored until sufficient capacity is available downstream. Examples of off-line storage include basins, tanks, and tunnels. If emptying of the storage areas is not possible, the stormwater may be pumped into or out of storage. Storage options include equalization systems, retention basins, aerated stabilization basins, and detention basins. Each

option is described below. However, the evaluation of the storage options will be based on on-line verses off-line and not on specific off-line storage facilities.

8.2.1 EQUALIZATION SYSTEMS

Some airports have large storage ponds or equalization facilities at the ends of runways. These ponds typically have a diversion valve to prevent uncontaminated runoff from entering the pond during the non-deicing months. The ADF contaminated runoff in these ponds is then transported to a sanitary sewer or treated on-site prior to discharge. Storage and equalization facilities precede treatment facilities to attenuate the flow to the treatment facilities. Normally, the treatment facilities cannot be economically designed to handle large surges in process flows or infrequent storm volumes (Stephenson et al.1998). Therefore, flow attenuation is necessary. Equalization basins are used to reduce fluctuations in the wastewater temperature, flow rate, and organic compound concentrations to the downstream treatment processes (Stephenson et al. 1998).

8.2.2 RETENTION BASINS

According to 40CFR section 122, to discharge runoff containing glycols to a WWTP, the receiving treatment plant must have the capacity to handle the hydraulic load as well as the additional biochemical oxygen demand associated with the deicing chemical (Federal Register 1995). To lessen both the increased hydraulic

and pollutant load on the WWTP due to ADF contaminated stormwater, retention basins located at the airport facility are an option. Retention basins can allow for the collection of large volumes of glycol wastes from pavement surface runoff. The basin must be large enough to “handle surface runoffs for winter months noting the decreased microbial activity during the winter season which is needed for biodegradation, plus additional capacity for runoff during thawing periods” (Federal Register 1995).

8.2.3 AERATED STABILIZATION BASINS

One option for airports to consider is to capture ADF storm water runoff in aerated retention basins. This could result in a greater degree of biodegradation on-site, reducing the BOD of the wastes. Continuous aeration of the retention (or detention) pond allows for faster biodegradation, which may reduce the capacity requirements (Stephenson et al. 1998). However, this treatment may require tremendous storage capacity, long retention times, and have aesthetic problems (Sills and Blakeslee 1991). Aerated stabilization basins are more or less a lagoon with mechanical or diffused aeration. Most basins use floating mechanical aerators (Stephenson et al. 1998). The wastewater enters at one end of the basin and exists at the other end after experiencing aeration. A facultative lagoon or clarifier to remove suspended solids often follows these basins. Aerated stabilization basins are gradually being phased out due to groundwater contamination problems (Stephenson

et al. 1998). The basins can be converted to activated sludge plants by installing a clarifier on the effluent end and pumping the sludge to the influent end.

8.2.4 DETENTION FACILITIES

One of the most common structural controls for storm runoff and pollution loading is the construction of local ponds (including wetlands) to collect storm runoff. The water is held long enough to improve its quality and released to receiving waters in a controlled manner (Moffa 1996). The controlled release attenuates the storm water flows and prevents shock loading the receiving waters.

9.0 TREATMENT, REUSE AND DISPOSAL

Storage alone will offer only flow attenuation and treatment alone will treat only a fraction of the storm water flow or must have such a large capacity to handle peak flows that the construction and operating costs are prohibitive. Therefore, combining the storage and treatment to find the best balance will provide the most cost effective solution for treatment of ADF contaminated storm water. This section discusses the treatment, reuse and disposal options for spent ADF. These options include on and off-site aerobic treatment, anaerobic treatment and recycling.

9.1 BIOLOGICAL TREATMENT

Biological treatment removes organic pollutants from the storm runoff either aerobically or anaerobically. For this treatment to be effective, the system must be operated continuously to maintain an active biomass or be able to obtain the biomass from a system that does operate continuously (Moffa 1996). Biological processes are sensitive and can be affected by variable flow conditions and high concentrations of nonbiodegradable solids in the stormwater runoff.

There are two types of biological treatment, aerobic treatment (treatment in the presence of oxygen) and anaerobic treatment (treatment in the absence of oxygen). The main goal of biological treatment is to reduce or mineralize organic compounds to carbon dioxide and water (Stephenson et al. 1998).

There are two types of biological reactors, suspended growth and fixed film reactors. Suspended growth reactors use mixing and hydraulic gradients to keep the microorganisms in suspension and to ensure that the microorganisms stay in contact with as much of the substrate as possible. The activated sludge process is an example of a suspended growth reactor. Fixed film reactors rely on microorganisms attaching themselves to a solid medium while the wastewater is trickled by the microorganisms as a film (Stephenson et al. 1998). Fixed film systems are often used when the influent wastewater has a very high concentration of substrate, "requiring a high cell density for sufficient biodegradation, and for anaerobic processes where cell growth rates are slower and more difficult to maintain" (Stephenson et al. 1998).

Fixed film systems are less susceptible to upsets from variable or intermittent flow rates because the organisms are held on the film and the organisms remain in the system (Stephenson et al.1998). Common examples of fixed film systems are the trickling filter and the fluidized bed reactor.

9.2 AEROBIC TREATMENT

Aerobic reactors use oxygen and microorganisms in a contained area in order to convert organic compounds to carbon dioxide and biomass. Aerobic reactors are very effective in treating organic wastewater although they produce more sludge than their anaerobic counterparts. Aerobic reactors are often used to treat large quantities of low strength wastewater to a very high degree (EFX Systems Inc. 1999). Aerobic biological treatment systems have been the main form of secondary treatment for municipal and many industrial wastewaters for the past half-century (Barnes 1995). Six common types of aerobic biological treatment systems can be seen in Figure 7. Although the systems operate differently, they all have the same goal of reducing the organic content of the waste in order to lower the BOD to a low enough concentration, suitable for discharge. The six processes in Figure 7 include both fixed film and suspended growth processes. The fixed film processes are land treatment, trickling filters and rotating biological filters. The suspended growth processes include wastewater stabilization ponds, aerated lagoons and activated

sludge. Many of these processes will be discussed in further detail in the evaluation section of this report.

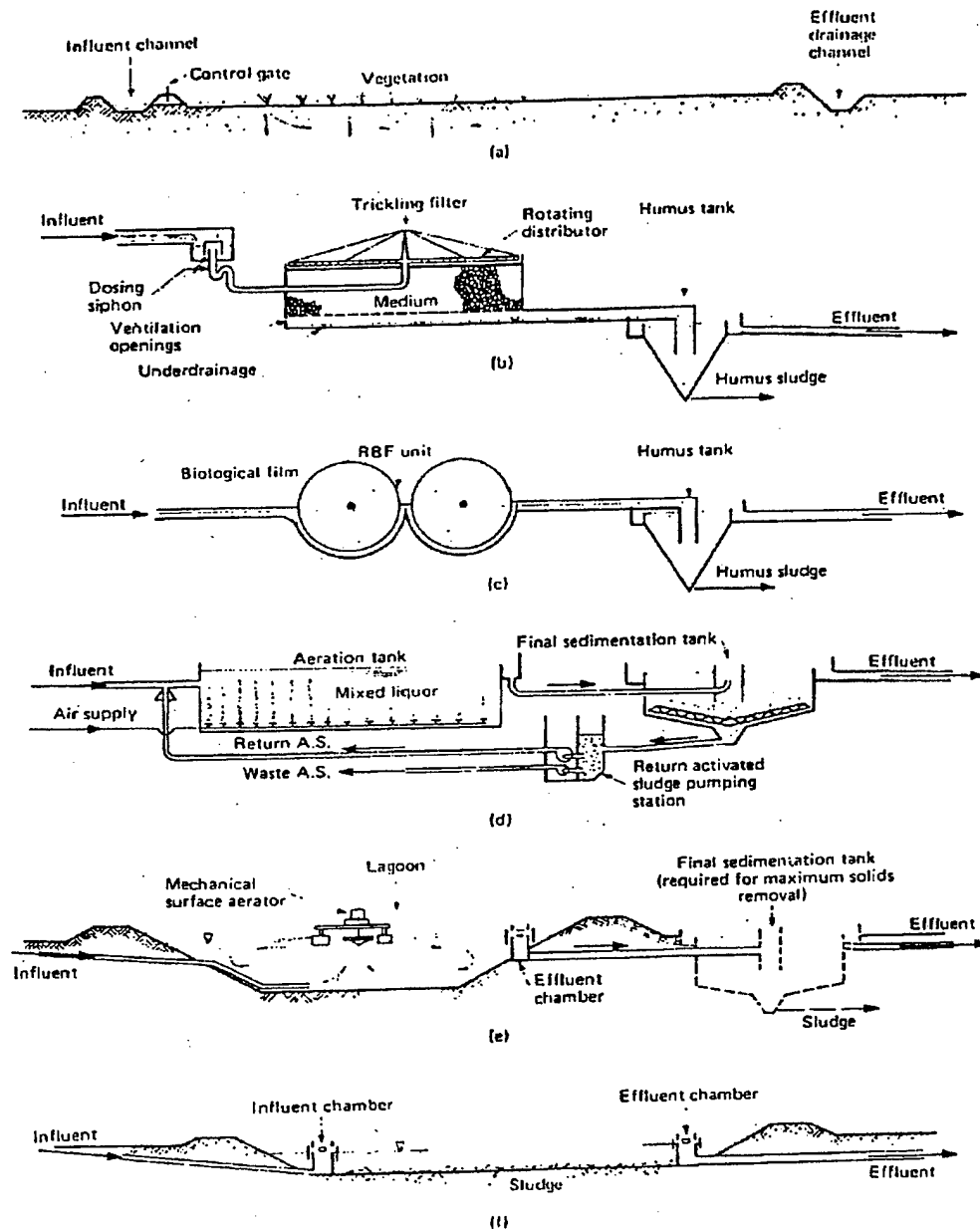


Figure 7: Diagrams of the Principal Biological Treatment Systems: (a) Land Treatment, (b) Trickling Filter, (c) Rotating Biological Filter, (d) Activated Sludge, (e) Aeration Lagoon, (f) Waste Stabilization (Oxidation) Pond
Source: Barnes 1995

To understand why some aerobic biological processes are appropriate for ADF treatment and why some are not, further discussion on the principles of biological treatment processes is necessary. Figure 8 shows a simplified aerobic process. The bacteria use some of the organic matter to grow new cells, breaking down the remainder to simple products in order to provide the energy needed for their growth and cell maintenance (Barnes 1995). Since the process is aerobic, the oxygen is an essential element. In treatment processes, the new bacteria cells must be removed and disposed of as sludge. One aim of aerobic treatment is to minimize sludge production through maximizing the proportion of organic matter degraded (Barnes 1995).

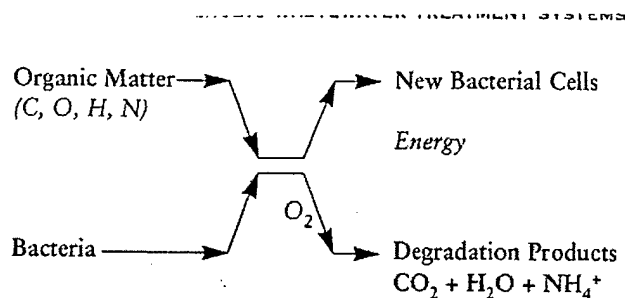


Fig 8: A Simplified Representation of the Action of Aerobic Bacteria Using Organic Matter as Their Food and Energy Source for Growth.
Source: Barnes 1995

The "Food to Microorganism Ratio" (F/M) is a measure of the amount of waste organic matter applied each day per unit of biomass in the system. A low F/M

ratio implies that the process produces less sludge per unit applied organic matter. The F/M ratio becomes important when analyzing the cost of aerobic treatment, whether it be onsite or the ADF sent to a POTW. But, if less sludge is produced, more oxygen is used, hence a larger capacity is required and the power costs increase (Barnes 1995).

Aerobic systems, like the POTWs that use them, are not designed to treat high strength wastes like ADF wastewater. Aerobic systems have low organic matter degradation rates as the temperature of the liquid decreases. Since the greatest treatment capacity is required during the winter, the rate of treatment is slow, requiring large systems. Studies have been conducted on the effectiveness of both activated sludge process (suspended growth) and trickling filters (attached-growth) for the treatment of spent ADF. These will be discussed later in the report,

An option for ADF treatment is release of the spent ADF to a wastewater treatment plant. One waste management alternative involves discharging ADF waste to a Publicly Owned Treatment Works (POTW) or to a base Wastewater Treatment Plant (WWTP). Routing the spent ADF to a POTW is the most common method of ADF treatment to date (Cummings 1995). However, POTWs are designed to treat low strength wastewaters to a very high degree. They are not designed to treat high strength wastewaters like spent ADF. Routing spent ADF to POTWs may negatively impact POTWs and the ADF contaminated stormwater occupies treatment capacity that may be reserved for residential growth (Barnes 1995). One of the most

frequent causes of poor effluent quality from WWTPs is upsets in the biological reactor due to changes in the wastewater characteristics because of industrial waste (Barnes 1995).

The type of biological process that occurs at a POTW or on-site helps to determine the proper ADF management. Each biological treatment process is different in terms of the load each process can handle, the amount of sludge the process produces, and the process efficiency. A comparison of activated sludge processes and trickling filters at WWTPs is included in the evaluation section of this report and the following two sections to show how one process may be more effective in treating ADF stormwater than the other.

9.2.1 TRICKLING FILTERS

Trickling filters have extremely high capital costs and they are limited in the degree of performance control. Once they are built, they cannot easily be adapted. Municipal trickling filters are sized based on an organic loading of 0.07-0.10 kg BOD m⁻³d⁻¹ (Barnes 1995). ADF has a BOD of over 20,000 mg/L and therefore the potential to shock load a trickling filter system.

9.2.2 ACTIVATED SLUDGE

In the activated sludge process, an aerated reactor grows a mass of biological solids that degrade the organic contaminants in the wastewater (Stephenson et al. 1998). These solids are settled and recycled back to the influent end of the reactor to increase the rate of organic matter degradation (Stephenson et al. 1998). A solids separator or a clarifier always follows the reactor to remove the biomass. The activated sludge process is the most complex of the aerobic treatment systems (Barnes 1995). An example of a typical activated sludge process is as follows. The return activated sludge is added to the incoming wastewater. This mixture is called “mixed liquor”. The rate of oxygen demand exerted by the bacteria in the system must be matched by the rate of supply by the aeration system. After the aeration tank, the wastewater flows to the sedimentation tank for separation of the biomass, also called activated sludge, from the mixed liquor. The result is a clarified effluent. Some of the settled sludge is recycled back to the front of the aeration tank to continue the process. The remainder of the sludge is treated and disposed of. Dried sludge is usually disposed of to a landfill. The excess solids create a materials management issue that will be discussed in a later section of this report.

9.3 ANAEROBIC TREATMENT

On-site anaerobic pretreatment of deicing wastes may be an effective alternative for airports. It has the potential to reduce high biosolids production and the energy costs for aeration associated with aerobic processes. Anaerobic treatment is the breakdown of organic matter in the absence of oxygen to methane and carbon dioxide. This can be seen in Figure 9. In recent years, anaerobic treatment has proven to be successful in the treatment of high volume, medium to high strength industrial wastewaters (McLean 1995). Anaerobic treatment has many advantages and disadvantages (Table 3). The important issue is whether anaerobic treatment is suitable for ADF wastewater. Anaerobic treatment is usually used when the wastewater has a biodegradable chemical oxygen demand (COD) concentration in the range of 2000-20000 mg/L (McLean 1995). A variety of anaerobic reactor configurations have been developed. These include the contact process, upflow anaerobic sludge blanket, anaerobic filters, anaerobic fluidized/expanded bed reactors and hybrid reactor systems (McLean 1995).

Table 3: Advantages and Disadvantages of Anaerobic Treatment
Source: Adapted from McLean 1995

Advantages	Disadvantages
Low Sludge Production	Long start-up time due to slow growth rate of anaerobic bacteria
Low operating costs	Moderate effluent quality (supplementary treatment required)
High loading rates can be achieved	Sensitive to chemicals, pH, variations, overloads
Low nutrient requirement	
Biomass can be maintained unfed for long periods of time	

Anaerobic organisms are more sensitive to pH and temperature than aerobic organisms (Stephenson et al. 1998). Anaerobic treatment is usually used as a first stage biological treatment process to reduce BOD from high concentrations to the 200 to 300 ppm range (Stephenson et al.1998).

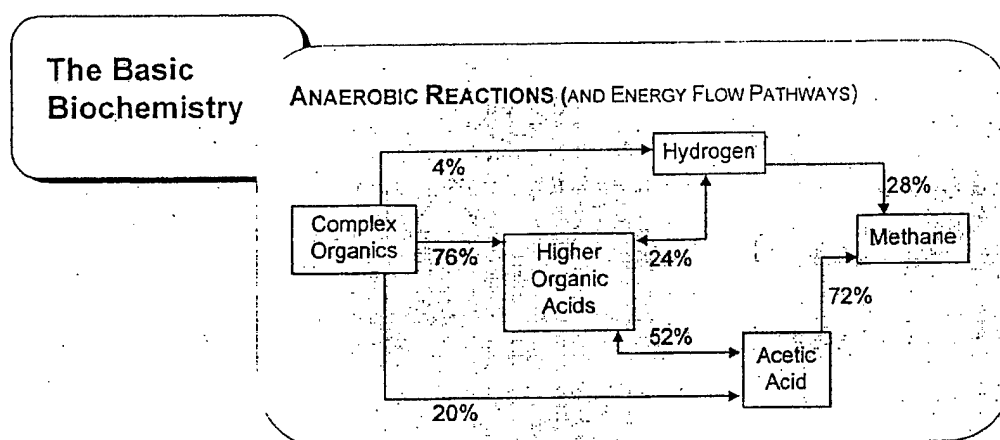


Figure 9: Anaerobic Reactions and Energy Flow Pathways
Source: EFX Systems Inc. 1999

9.3.1 ANAEROBIC FLUIDIZED/EXPANDED BED REACTORS

In these reactors, as seen in Figure 10, biomass is retained within the reactor as a biofilm attached to a fine-grained media like sand, granular activated carbon, or plastic (McLean 1995). The media expands when wastewater flows through the system. According to McLean, the wastewater industry has had a difficult time with this technology due to high pumping energy requirements, high media costs, and start up difficulties. However, these systems are insensitive to shock loads, have extremely high removal capacities, and the carrier material can be chosen for specific application to improve performance. Loading rates range from 30-60 kg COD m⁻³d⁻¹ with hydraulic retention times of only a few hours (McLean 1995).

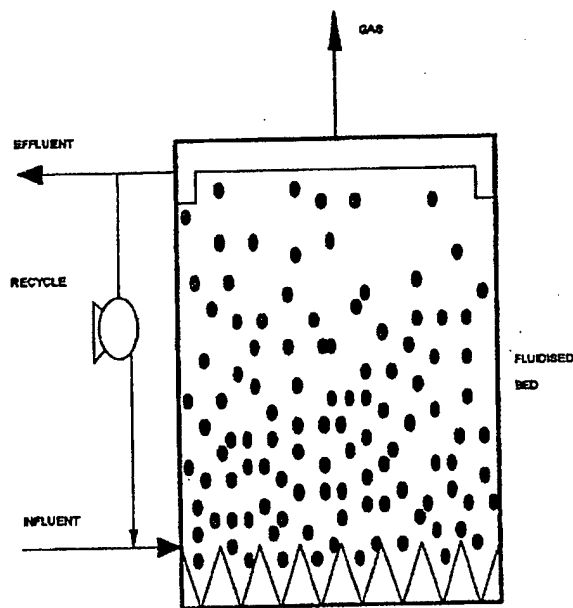


Figure 10: Schematic Representation of an Anaerobic Fluidized/Expanded Bed Reactor

Source: McLean 1995

9.3.2 UPFLOW ANAEROBIC SLUDGE BLANKET

As seen in Figure 11, the main elements of the upflow anaerobic sludge blanket (UASB) are the influent distribution system at the base of the reactor and a three-phase solids/liquid/gas separator at the top (McLean 1995). The influent wastewater flows upwards through a blanket of active biomass that is suspended by the liquids flow velocity. The development of a flocculent sludge with food settling characteristics is key to the UASB process (McLean 1995). The UASB is somewhat sensitive to shock loads and the formation of granular sludge may take months. COD removal rates of 70-90% at loading rates between 2 and 24 kg COD m⁻³d⁻¹ with hydraulic retention times as low as 8 hours are reported (McLean 1995). UASBs are the most extensively used high-rate anaerobic reactors (McLean 1995). According to a study at the University of Ottawa, dilute aircraft deicing fluid wastewater at 20 g COD/L can successfully be treated in upflow anaerobic sludge blankets with COD removal efficiencies of 85 percent (Darlington et al.1998).

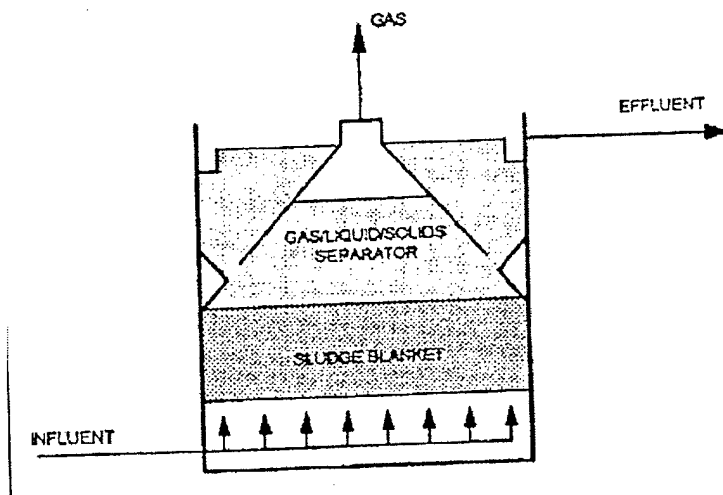


Figure 11: Schematic Representation of an Upflow Anaerobic Sludge Blanket Reactor (UASB)

Source: McLean 1995

9.4 ANAEROBIC TREATMENT APPLICATION

Two proprietary anaerobic systems were evaluated for this report. They include AnAerobic Inc.'s Mobilized Film Technology and EFX Systems Inc.'s Fluidized Bed System. Both systems are discussed in the following sections.

9.4.1 ANAEROBIC MOBILIZED FILM TECHNOLOGY

AnAerobics Inc. has developed an anaerobic Mobilized Film Technology (MFT) that provides rapid conversion of the glycol organics to energy as natural gas, leaving an effluent liquid equivalent to sewage for discharge to POTWs (Cummings 1996). AnAerobics MFT was evaluated as one of two on-site anaerobic treatment options.

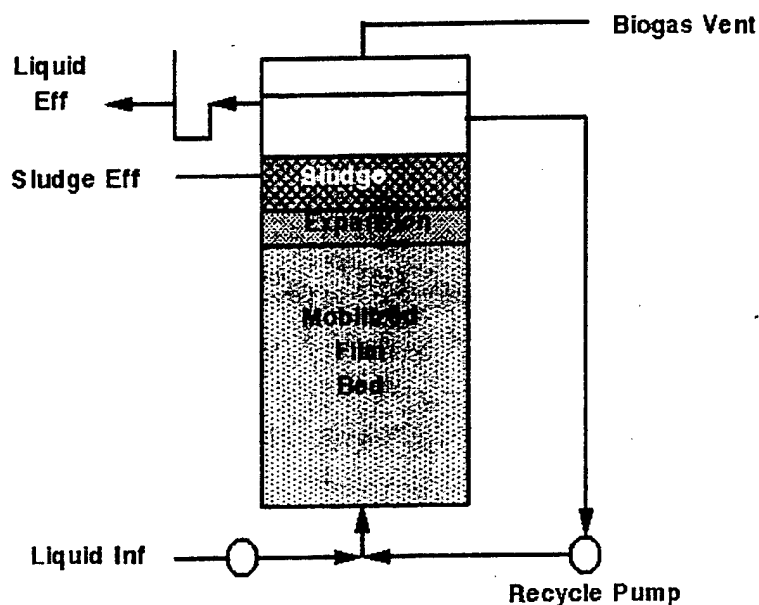


Figure 12: Schematic of AnAerobics Inc's, MTF Anaerobic Attached Film Expanded Bed Technology Used to Treat Spent ADF.
Source: AnAerobics Inc. 2000

The MFT process uses the anaerobic attached film expanded bed technology. The active microorganisms of the system become attached to a small diameter inert support media forming a thin film. The film prevents the active microorganisms from escaping from the system (Cummings 1996). As seen in Figure 12, the contaminated wastewater is pumped directly into the recycle system and the treated liquid overflows from the top of the reactor. Sludge produced migrates to the top of the bed and is removed by gravity overflow. The sludge production is one tenth that of aerobic systems (Cummings 1996). Biogas is vented from the top of the reactor and is available for use as an energy source (Cummings 1996).

9.4.2 EFX SYSTEM ANAEROBIC FLUIDIZED BED SYSTEM

A schematic of a typical anaerobic fluidized bed system can be seen in Figure 13. First, the contaminated water is pumped upwards through a bed of activated carbon. The contamination (glycol) is “coated” by a thin film of microorganisms that convert the contamination into methane, carbon dioxide and some new biomass (sludge). EFX Systems Inc.’s fluidized bed bioreactor was evaluated using the criteria as one of the on-site anaerobic treatment options.

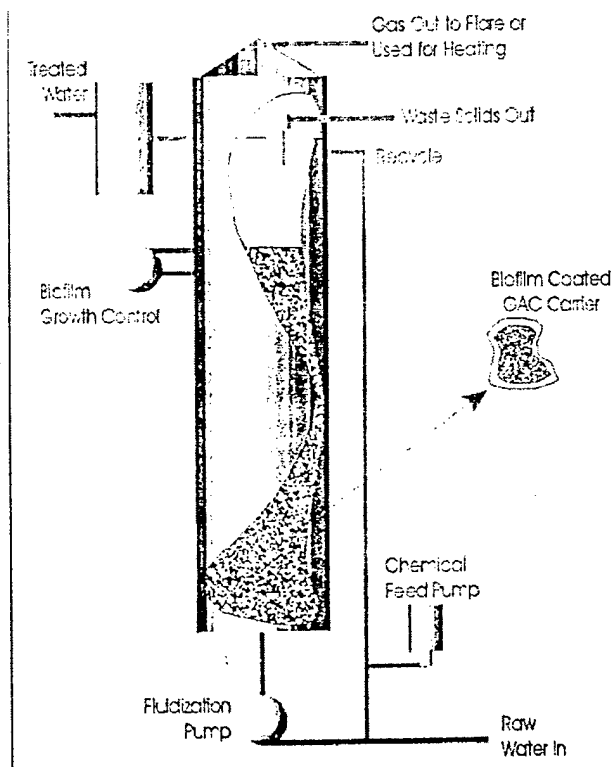


Figure 13: Anaerobic Fluidized Bed System
Source: EFX Systems Inc. 1999

9.5 RECYCLING

ADF recovery systems are based on a series of processes including primary filtration, ion exchange or nanofiltration, distillation and reverse osmosis. A schematic of a typical recycling system can be seen in Figure 14. In order to obtain information for a specific ADF recycling systems, Mr. Jim Hamilton of Glycol Specialists was contacted.

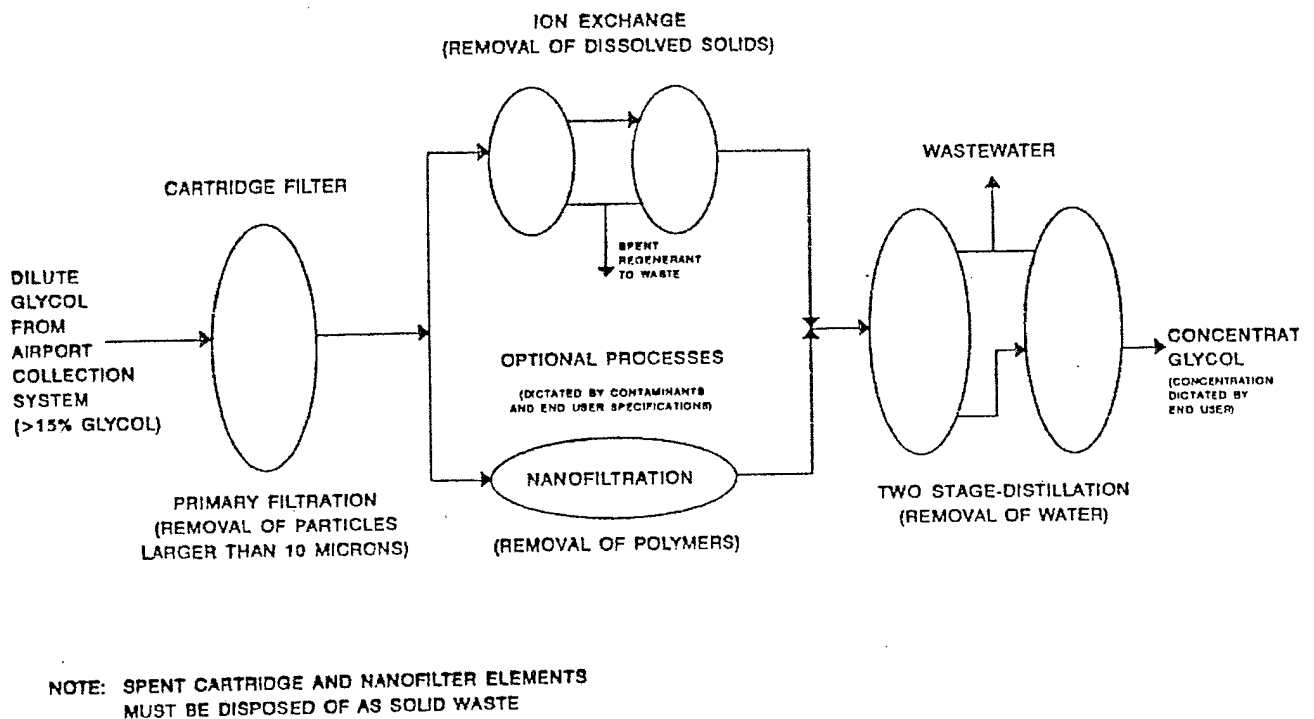


Figure 14: Schematic of a Typical Glycol-Recycling Unit
Source: US EPA 1995

The purpose of primary filtration is to remove suspended solids entrained in the ADF (US EPA 1995). Filtration is a physical process, in which solids suspended in a liquid are separated from that liquid by passage through a porous medium. In all filtration processes, a pressure differential is introduced through gravity, vacuum, pressure or centrifugal force (Noll, Haas et al. 1985). Ion exchange is used to remove dissolved solids and nanofiltration is used to remove polymeric additives that were used in the glycol-based ADF (USEPA 1995). Reverse osmosis is used to concentrate dilute streams (<15% glycol) prior to distillation. The key process in ADF recovery is distillation. Distillation is a unit operation used by an industry to separate, segregate, or purify a liquid organic product stream (Noll, Haas et al. 1985).

10.0 CURRENT ADF DRAINAGE PRACTICES

In order to suggest deicing fluid treatment options, it is important to understand the current drainage practices of Air Force Bases and commercial airports. After compiling data from various Air Force Bases and commercial airports, one can attempt to generalize the deicing drainage situation. This will aid in determining a solution to the ADF management dilemma. Appendix C shows numerous bases and commercial airports around the world and the variety of ADF drainage practices. The data in Appendix C was obtained through the National Defense Center for Environmental Excellence (NDCEE), Ecology and the

Environment Inc, AFCEE, journal articles, and telephone inquiries. NDCEE performed deicing operation case studies on various commercial airports. NDCEE collected data on chemical use, equipment, containment systems and runoff treatment (if applicable). Ecology and the Environment Inc sent questionnaires to various AFBs regarding the types and amounts of deicing chemicals used. Because this study was performed in 1997, the information was checked and updated through contacts at various AFBs. Discussions with base civil engineers showed that the information obtained in the Ecology and the Environment Inc. study reflects the current practices at the AFBs. Commercial airports were crosschecked through journal articles.

Concentrating first on Air Force Bases, the average annual usage of propylene glycol ranges from 1100 gallons to 35,000 gallons. As one can see in Figure 15 and Figure 16, there does not seem to be a correlation between glycol use and temperature and or snowfall. Therefore, glycol use is dependent on some other variable, such as the number of sorties flown or the size of the aircraft.

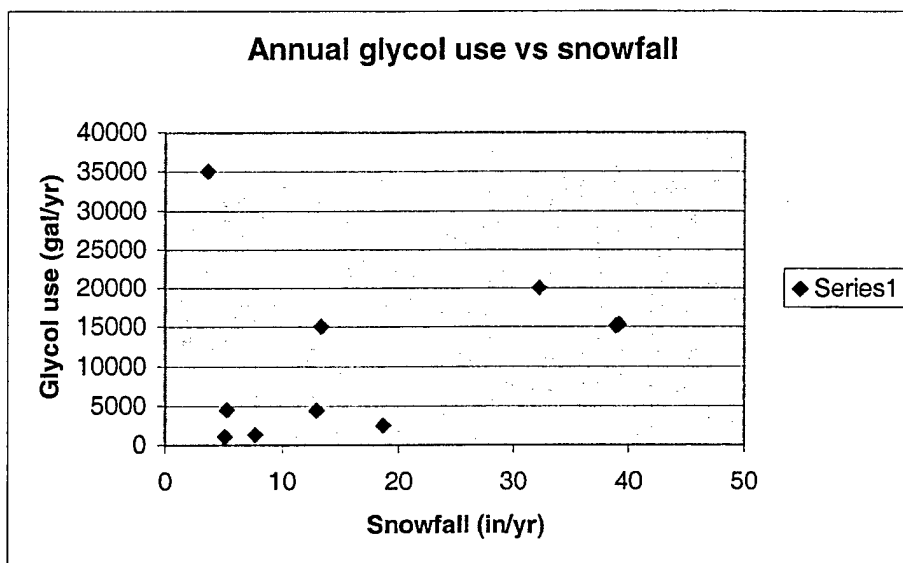


Figure 15: Average Annual Glycol Use at Various Air Force Bases versus Snowfall

Source of Data: Ecology and the Environment and The National Defense Center for Environmental Excellence 1997

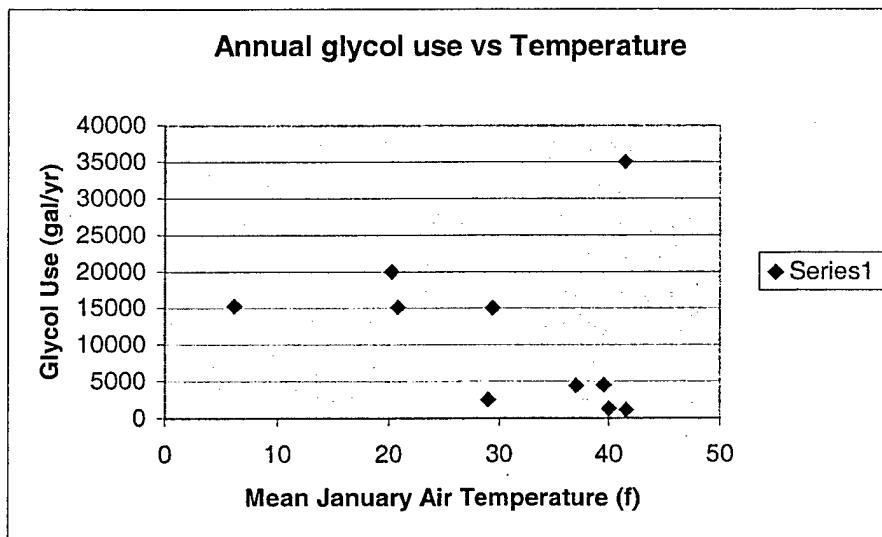


Figure 16: Average Annual Glycol Use at Various Air Force Bases versus Temperature

Source of Data: Ecology and the Environment and The National Defense Center for Environmental Excellence 1997

In terms of the treatment of spent ADF, only three of the thirteen bases that provided data treat the spent fluid prior to discharge into surface water outfalls. The three bases that perform some level of treatment of spent ADF include Ellsworth AFB South Dakota, Whiteman AFB Missouri, and Offutt AFB Nebraska. At Ellsworth AFB, ADF runoff is collected through a single outfall point that drains to a retention pond with an oil/water separator and an aeration unit. The "treated" water is then discharged to surface waters. Whiteman AFB has manually operated diversion valves in the storm sewer to direct deicing fluid to an on-base industrial wastewater treatment plant (IWWTP). The IWWTP sends its treated water to an on-base water treatment plant. Offutt AFB has a three-way valve in its storm sewer. One option is to send the runoff to the city of Omaha Publicly Owned Treatment Works (POTW). If the concentration of glycol in the storm water is above prescribed limits, the water is stored in underground storage tanks (UST's). When deicing is not in progress, water runoff flows to the storm sewer and ultimately to a surface water outfall.

Appendix C also shows the different sanitary sewer options available for each base. The sewer options will aid in determining a solution based on the loadings available for each WWTP. Many bases have their own IWWTP or WWTP. Of the thirteen AFB's that provided data, five have on base wastewater treatment plants. The other bases use POTWs for their sanitary wastes.

The Air Force only uses a fraction of the amount of propylene glycol used by commercial airports. Commercial airports range in glycol use from 17,000 gal/yr to a million gallons of propylene glycol used per year. Possibly due to the greater usage of ADF, commercial airports are more advanced in ADF treatment. Every commercial airport that provided data performed some sort of ADF treatment prior to discharge. For example, at Lester P. Pearson International Airport in Toronto Canada, the spent ADF is diverted to underground storage tanks where the glycol concentration is monitored. If the glycol concentration is less than 100 mg/L then the water may be released to surface water. If the glycol concentration is greater than 100 mg/L, the contaminated water is diverted to a sanitary sewer and treated at a POTW. The 100mg/L limit for Lester P. Pearson Airport is not a standard for all airports but rather a function of the receiving body of water. For example, at Albany International Airport in New York, the maximum allowable propylene glycol concentration for discharge into surface water or for irrigation is 1 ppm. Other commercial airports with spent ADF treatment systems include Pittsburgh International Airport (PIA) and Denver International Airport (DIA). Both use large quantities of ADF and have similar drainage techniques. PIA collects spent ADF in above ground stainless steel, poly-lined tanks. A tanker truck pumps the tanks out and the contaminated water is treated at an on-site processing plant prior to discharge. DIA diverts runoff to detention basins where the water is tested and options determined. The water may be sent to a wastewater treatment plant,

discharged to surface water or recycled. Although the practices at DIA and PIA are interesting and relevant to this study, their treatment options may not be cost feasible for small quantity generators like the various Air Force bases around the world. For example, DIA's multi-option systems cost over \$17 million dollars to implement (Evans 1996).

10.1 GENERALIZING CURRENT PRACTICES

The above evaluation of the ADF management practices that currently exist at Air Force bases was used to generalize the ADF management practices for this report. An annual glycol usage of 30,000 gal/yr was used to determine the cost analysis for the treatment options in this report. Thirty thousand gallons per year was chosen based on an average of the AFBs evaluated for this report. Because commercial airports use millions of gallons of deicing fluid per year, information from commercial airports is informative but cannot be realistically applied to AFBs. Most untreated ADF contaminated stormwater has a glycol concentration of 10% (Strong-Gunderson 1995). For this evaluation, it was assumed that the ADF concentration in stormwater is 10%. Based on 30,000 gallons of ADF used per year, this equates to 300,000 gallons of contaminated stormwater.

Most AFBs discharge their stormwater to local POTWs or on-base WWTPs. The majority of WWTPs and POTWs use activated sludge for their biological systems. The off-site aerobic treatment facility option assumes ADF stormwater is

discharged directly to a POTW or base WWTP that is operated with an activated sludge biological system.

11.0 CRITERIA

The following airport flight constraints were considered when choosing the criteria used to analyze the treatment options for ADF.

- Large bodies of water cannot be in the flight path because they attract wildlife. This could pose serious safety hazards.
- Storm water is produced intermittently and therefore flow rates are variable
- Deicing is often performed intermittently, resulting in a wide variety of glycol concentrations in the stormwater
- Because deicing is performed during freezing temperatures, the kinetics of the microbial processes used to treat the stormwater could be very slow
- Little attention to the treatment option is preferred

The following section discusses the criteria used in this report to evaluate the various treatment alternatives.

11.1 COST

With military budget cutbacks, minimizing cost while not compromising safety and standards is a major concern. Both capital costs and operation and maintenance costs of the equipment use were evaluated.

11.2 NPDES REGULATION

The Clean Water Act requires the EPA to establish permit requirements under the National Pollutant Discharge Elimination System (NPDES) for airport operations, including ADF (US EPA 1995). Dischargers must meet the National Pollutant Discharge Elimination standards in order to obtain permitting for the discharge. It is essential that the deicing fluid treatment technology adhere to these standards. Looking at a case study of Logan Airport in Boston will help one to understand the importance of the management option adhering to permit requirements because military and government agencies must adhere to NPDES regulations.

Logan Airport is a major international airport that is surrounded by Boston Harbor. There are 49 stormwater outfalls at Logan Airport discharging to Boston Harbor (Ellis et al. 1994). The work conducted in order to obtain a NPDES Discharge Permit Application associated with Industrial Activities at Logan Airport included wet weather sampling, stormwater loading estimates, receiving water analysis and development of a BMP plan. Focus was placed specifically on the impact of ADF contaminated stormwater. Table 4 shows the single event glycol loading for a 50 percent glycol/50 percent water solution. The worst case-loading situation would occur assuming 20 percent of the annual glycol usage occurs during one storm event.

Table 4: Single Event Glycol Loadings for Logan Airport

Source: Ellis et al. 1994

Condition	North Outfall	West Outfall
Single storm of 1.0 inch equivalent rainfall	4000 gallons	12000 gallons
Twenty percent of annual usage	24,500 gallons	73,500 gallons

Logan Airport had to show that the above loading did not pose a threat to Boston Harbor. In other words, they had to show that the dissolved oxygen concentration would not fall below 5mg/L due to the glycol loadings on the harbor. Assuming no reaeration and that oxidation occurs at a rate based on a water temperature of 10 degrees Celsius, the DO concentration would be depleted from 9 mg/L to 5.2 mg/L (Ellis et al. 1994). This assumed that glycol is mixed over a 5-day period with harbor water equivalent to the volume of the section of the harbor north of the airport to a certain point. This was enough to allow Logan airport to receive a permit for discharge into Boston Harbor. Ellis concluded that the concentration of glycol-based deicers discharged from Logan Airport was not toxic to marine organisms nor would the deicers adversely impact dissolved oxygen concentrations in the harbor (1994).

11.3 PERFORMANCE

To not adversely affect receiving waters, it is necessary to remove a certain percentage of the glycol from the site runoff water. Wastewater effluent requirements in the United States are set by federal and state agencies. Natural or background conditions in the receiving water are used to determine selected parameter values for a given stream or lake (Schroeder 1977). For example, discharges into the Sacramento-San Joaquin Delta has a BOD5 daily maximum of 90 mg/L (30 day average of 30 mg/L) and the discharge shall not cause the dissolved-oxygen concentration in the river to fall below 5.0 mg/L (Schroeder 1977). Trickling filters can rarely meet this criterion and many activated sludge processes meet it only intermittently (Schroeder 1977). Also, in the evaluation of the storage options, the ability of the storage alternatives to attenuate flow needs to be considered.

11.4 MANAGEMENT AND MAINTENANCE

Due to Air Force manpower concerns, the operability and ease of the ADF treatment system is important. Manpower cutbacks in the Air Force are leading to a lack of personnel available to solely operate an ADF treatment system. Therefore minimal management and maintenance of such systems is important.

12.0 EVALUATION OF STORAGE OPTIONS

The following section evaluates each treatment option based on the various criteria. Each section is organized according to criteria, followed by the treatment options.

12.1 COST

12.1.1 IN-LINE STORAGE COST

To maximize the benefit of in-line storage, it can be combined with some form of treatment. If not, the benefit of in-line storage is merely flow attenuation. If the storage is combined with an end of the pipe treatment, the flow attenuation will aid in the equalization of the load to the treatment process. This will help minimize the cost and size of the treatment facility (Moffa 1996).

12.1.2 OFF-LINE STORAGE COST

Normally, the treatment facilities cannot be economically designed to handle large surges in process flows or infrequent storm volumes (Stephenson et al.1998). Therefore, flow attenuation is necessary. Equalization basins are used to reduce fluctuations in the wastewater temperature, flow rate and organic compound concentrations to the downstream treatment processes (Stephenson et al.1998). Costs vary depending on the type of storage used.

12.2 NPDES REGULATION

12.2.1 IN-LINE STORAGE REGULATION

In-line storage is an attractive storage option due to its minimal land requirements. However, in-line storage is most easily installed during facility construction.

12.2.2 OFF-LINE STORAGE REGULATION

Airports have certain building restrictions to ensure safe flying conditions. Bodies of water attract birds, which are very dangerous to aircraft flight. Therefore, if an off-line storage facility were constructed, it would have to be located far from the runways.

12.3 PERFORMANCE

12.3.1 IN-LINE STORAGE PERFORMANCE

Even without on-site treatment, flow attenuation will help equalize the loading to the receiving water or POTW and reduce the peak flows and possible disturbance to the natural ecosystem (Moffa 1996). For example, at Denver International Airport, in-line storage and flow diversion techniques intercept 80 percent of the ADF to prevent it from entering the local receiving waterbody (US EPA 1999).

12.3.2 OFF-LINE STORAGE PERFORMANCE

Equalization of the wastewater flow rate results in more uniform effluent quality for downstream units and can benefit the biological treatment performance (Stephenson et al.1998). If the off-line storage is aerated, three major biological processes occur simultaneously. Organic solids accumulate on the bottom and are degraded by anaerobic bacterial degradation, organics are removed from suspension by aerobic bacterial metabolism, and algae growing on the surface of the lagoon utilize the nutrients released in these two processes. The limitation is the rate oxygen can be produced through photosynthesis (Schroeder 1977). This is a function of light intensity and temperature. Deicing occurs during the coldest times of the year. Low water temperatures decrease the rate of photosynthesis, making the organic conversion rate low and the lagoons can become storage tanks rather than biological reactors (Schroeder 1977). Sudden increases in temperature during the spring will create odor problems due to the increased activity of the microorganisms and the high organic load in the system. Table 5 shows the loading rates and BOD removals of oxidation ponds. Based on the high BOD values for ADF, oxidation ponds may not be effective. Their main benefit is flow attenuation.

Table 5: Loading Rates and BOD Removals of Oxidation Ponds
Source: Schroeder 1977

	Loading Rate, g/m²*d		Percent BOD₅ Removal	
Type of Pond	Average	Cold	Average	Cold
Aerobic	9.0-13.5	6.7	80-95	70
Facultative	2.8-5.6	1.7	80-95	70
Facultative-aerated	4.5-11.2	3.4	80-95	70

12.4 MANAGEMENT AND MAINTENANCE

12.4.1 IN-LINE STORAGE MANAGEMENT AND MAINTENANCE

In-line storage requires a regular maintenance program to ensure that the system functions properly. Systems should be inspected to remove debris within 24 hours of a significant rainfall or snowmelt since heavy storms may clog the drainage system.

12.4.2 OFF-LINE STORAGE MANAGEMENT AND MAINTENANCE

Similar to in-line storage, off-line storage also requires some level of management and maintenance. Regular maintenance includes the removal of debris from the inlet and outlet of the system along with ensuring a clean, well-maintained appearance (Urbonas et al. 1993). To the public, aesthetics are extremely important and therefore it is wise to properly maintain the area around and in the off-line storage facility.

13.0 EVALUATION OF TREATMENT OPTIONS

This section evaluates each treatment option based on the various criteria. Each section is organized according to criteria, followed by the treatment options.

13.1 COST

13.1.1 AEROBIC TREATMENT COST

In order for a POTW to accept spent ADF, the POTW charges airports a fee. At Albany International Airport, the airport paid approximately \$750,000 per year to transport and treat spent ADF at a POTW (Harrison 1998). POTWs charge airports fees for treatment due to the increased needs of the POTW as a result of the spent ADF load. Sending spent ADF to a wastewater treatment plant increases the plants electrical costs, biosolids (sludge) generation, chemical costs, operation costs and disposal costs.

A variety of operational problems attributed to ADF waste streams have been reported at several POTWs (Jank et al. 1974, Krumsick et al. 1994). For example, DIA sends some of its ADF wastewater to a local POTW. The POTW charges the airport seventeen cents per gallon of glycol-contaminated stormwater treated because of the high biological oxygen demand requirements (Evans et al. 1996). The local POTW imposes peak concentration limits (19 mg/L) and a total annual receiving limit (500,000 gallons) for effluent received from DIA (Evans et al. 1996). The maximum amount of BOD that can be released to the local POTW from DIA is

limited to 5,400 kg/day (Backer, Smith et al. 1994). The total annual cost for the POTW to treat the DIA deicing fluid contaminated storm water was about \$800,000 per year (Evans 1996).

If an Air Force Base uses 30,000 gallons of ADF per year, and an average of 10% ADF is contained in the stormwater, this results in 300,000 of contaminated stormwater. The cost to discharge the contaminated stormwater, untreated to a POTW, based on seventeen cents per gallon of glycol-contaminated stormwater, is approximately \$51,000/yr.

13.1.2 ANAEROBIC TREATMENT COST

Anaerobic reactors are less expensive to operate than aerobic reactors. The EFX Anaerobic Fluidized Bed and Anaerobic MFT were analyzed for this report. According to Roger Wens, president of EFX systems, an anaerobic fluidized bed system, consisting of one reactor 14 ft (4 m) in diameter and 35 ft (11 m) high, costs about \$150,000 annually (Civil Engineering 1999). This cost assumes a twenty-year operating life and includes all operations and maintenance costs to treat 300,000 gallons of contaminated stormwater.

At Albany Airport, the anaerobic EFX system has saved over \$3.1 million compared to the closest option (aerobic treatment) when compared on a present worth basis at 8% interest over 20 years (Civil Engineering 1999). The capital cost

of the anaerobic system was less than 65% of the aerobic option. Figure 17 is a photograph of the anaerobic system EFX installed at Albany International Airport.

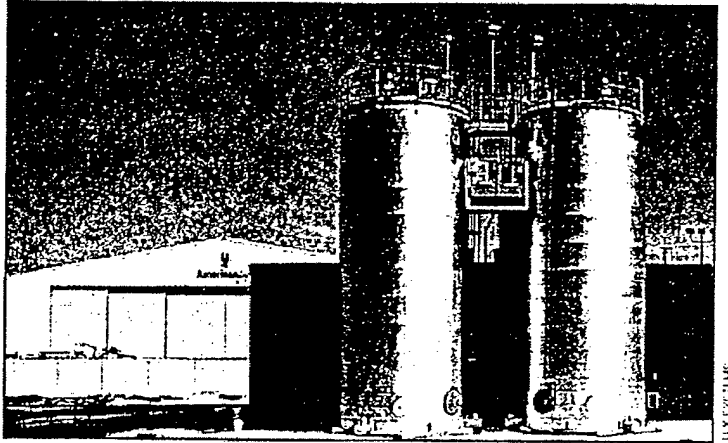


Figure 17: An Anaerobic Fluidized Bed Biological Treatment System at Albany International Airport in New York.

Source: Civil Engineering 1999

For the AnAerobics Inc. MFT Treatment Technology, total costs of the capital, operation and maintenance of the process can be as low as \$0.25 per gallons of stormwater (AnAerobics 1999). For an Air Force Base using 30,000 gallons of ADF per year, and a 90% dilution, 300,000 gallons of ADF contaminated stormwater is produced per year. The total cost would be approximately \$75,000 per year.

13.2.3 RECYCLING COST

According to Patton Harrison, an environmental engineer for American Airlines, “recovery and recycling facilities are very expensive to build and operate” (US EPA 1998). He feels that the capital cost will never be recovered by reselling the product and therefore the airport will have to pay for the capital cost through

landing fees. This is a valid point, but recovery of collected ADF may be cost effective when the glycol concentration is 15% or greater (US EPA 1995). The greatest annual cost is the cost for the energy used in the distillation process. Distillation equipment is expensive and recovery by distillation is energy-intensive, with nominal energy requirements being 250 to 1200 BTU/lb of feed (US EPA 1995). The cost for recovering collected ADF, assuming the used ADF is 28% glycol, is about 35 cents per gallon (Hamilton 2000). The greatest annual cost is the energy used in the distillation process. Assuming an annual ADF usage of 30,000 gallons and a contaminated stormwater total of 300,000 gallons per year, a recycling unit would cost about \$105,000 per year. This value takes dilution into consideration and assumes a value equivalent to that treated by the aerobic, anaerobic and no treatment options. Also, the benefit from selling the recycled glycol is included in the cost.

The recycled glycol may be sold to chemical manufacturers for use in other glycol products such as anti-freeze or synthetics. It usually cannot be used as ADF again as the equivalent to virgin ADF due to the Society of Automotive Engineers (SAE) safety standards. The market price for recycled ADF is \$3.40/gallon (Liu 1998). Assuming a recovery of 15,000 gallons of glycol per year, a profit of approximately \$51,000/year may be made.

Non-uniform application of glycols may result in the ADF recovery system not being cost effective due to the requirement of multiple systems. ADF recovery

process performance is uniformly good. However, individual airport –specific conditions and economic considerations will be the defining factors in the suitability of ADF recovery, not technology-based issues or process performance (US EPA 1995). The Air Force uses fairly uniform ADF application and therefore, uniformity is assumed not to be an issue.

13.2 NPDES REGULATION

13.2.1 AEROBIC TREATMENT REGULATION

When an airport discharges spent ADF directly to a POTW, the airport increases the risk of violating the discharge permits. The airport is “gambling” with the hope that the spent ADF does not shock the POTW’s system. For example, many POTWs will not accept waste with a glycol concentration of greater than 5% (Strong-Gunderson et al. 1995). Most untreated ADF contaminated stormwater has a glycol concentration greater than 10 percent. Assuming a flow attenuation device is used, aerobic treatment at a POTW or WWTP can meet NPDES regulation.

13.2.2 ANAEROBIC TREATMENT REGULATION

On-site anaerobic treatment is a pretreatment option that can be used prior to sending the stormwater to a POTW or base WWTP for polishing. It cannot be assumed that on-site anaerobic treatment of ADF contaminated stormwater is

sufficient for the stormwater to be discharged into lakes and streams. The on-site treatment merely decreases the load placed on the POTW or base WWTP. Although, in some cases, anaerobic treatment can treat ADF contaminated stormwater to levels appropriate for discharge. For example, at Albany International Airport the effluent glycol concentration cannot exceed 1ppm (1 mg/L) (Civil Engineering 1999). An on-site anaerobic treatment facility resulted in an effluent of 0.3 ppm (0.3 mg/L). The influent ADF stormwater was approximately a 5% glycol solution. This shows that NPDES regulations may be met without sending the treated stormwater to a POTW but further treatment depends on the influent conditions.

13.2.3 RECYCLING REGULATION

Despite the effectiveness of a recycling system, there will always be a discharge to the POTW of some waste from the recycling system. Therefore, the airport will still have many of the same discharge issues as the off-site aerobic treatment option. (Cummings 1993).

13.3 PERFORMANCE

13.3.1 AEROBIC TREATMENT PERFORMANCE

At high concentrations, aerobic systems are not designed to treat high strength wastes such as those associated with ADF (Cummings 1993). Most WWTPs using activated sludge are designed to treat BOD levels of 200 to 300 mg/L (Cummings 1993). Also, the organisms used in aerobic processes have low decay rates at cold water temperatures. Since the greatest treatment capacity is required during the coldest times of the year, and the rate of aerobic treatment is slower at that time, large treatment systems or the need for large retention ponds to temporarily store the spent ADF prior to treatment is required (Cummings 1993). A major disadvantage of aerobic systems is their high production of sludge. In general, for every pound of COD aerobically removed 0.5 pounds of sludge are produced (Cummings 1993).

Discharging spent ADF directly to a POTW is viable if the POTW has the ability to accept loads of that caliber. The following section discusses the best type of POTW to accept ADF contaminated stormwater. A study was conducted to demonstrate the feasibility of treating stormwater contaminated with airport deicing fluid (ethylene glycol) in a batch-loaded aerobic fluidized bed reactor (Safferman et al. 1998). Treating the contaminated storm water in batches eliminated the operational problems common to a continuously loaded aerobic fluidized bed

reactor. Therefore, aerobic fluidized bed reactors have the potential to treat large quantities of high strength wastewater that is intermittently produced (Safferman et al. 1998). Figure 18 shows a schematic of an aerobic fluidized bed reactor.

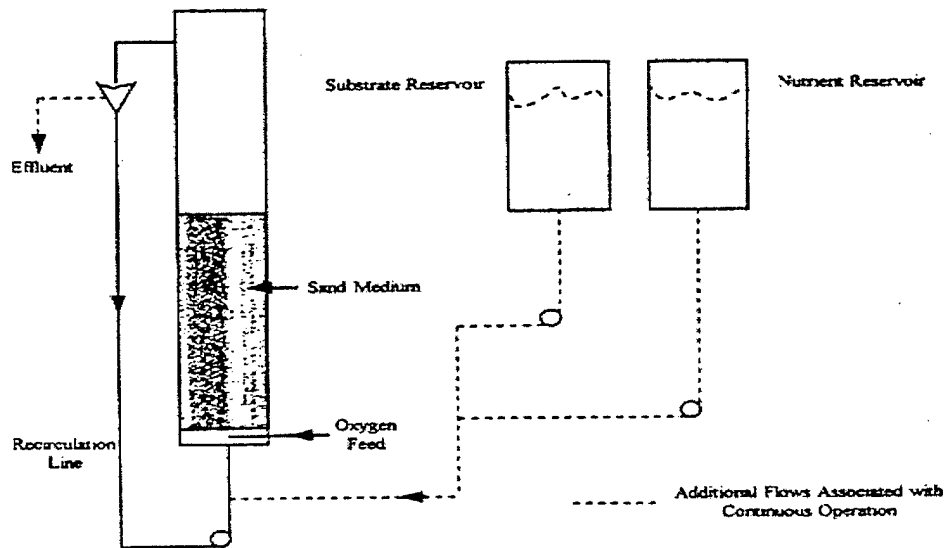


Figure 18: Schematic of an Aerobic Fluidized Bed Reactor
Source: Safferman et al.1998

Wastewater treated in a fluidized bed reactor enters the bottom of a reactor packed with a granular medium. The up-flowing wastewater expands the medium so it becomes suspended and completely surrounded by the water. The surface of the medium becomes coated with bacteria. The resulting installation is expected to be two to three times larger than a continuously operated fluidized bed reactor but the same size as a conventional activated sludge instillation. An additional benefit is low quantity of sludge production (Safferman et al.1998).

Holladay et al. compared the performance of an aerobic fluidized bed reactor with that of an aerobic packed bed tower and a stirred-tank process for the treatment of phenolic waste liquors (1978). The fluidized bed reactor had a degradation rate that was 1.8 to 3.5 times higher than the fixed bed process and 4.0 to 8.5 times higher than the suspended growth process (Holladay et al. 1978). Holladay's research also showed that aerobic fluidized bed reactors are very effective in recovering from shock organic loadings. Disadvantages of aerobic fluidized bed reactors are the high level of oxygen required to support the large quantity of biomass and the need to clean the media of excess biomass (Safferman et al. 1998). According to Safferman, a batch-loaded aerobic fluidized bed reactor with effluent recycle has the potential to minimize the large oxygen and cleaning requirements. Another advantage is the low maintenance requirements relative to other compact processes. Cost was not considered and site specific conditions and pilot-scale testing has not been done.

Sabeh and Narasiah (1992) studied the degradation rate of aircraft deicing fluid in a sequential biological reactor. They found that ADF can be treated biologically and that the rate of removal can be significantly affected by organic load and temperature. Shieh, Lepore, and Zandi (1998) found that biological fluidized bed technology is capable of TOC removals >96% at empty bed HRTs as short as 1.7 hours and at TOC loadings as high as 0.88g/Lday. Aerobic biological fluidized bed reactors are capable of sustaining good TOC removal during single pulse

loadings with a pulse magnitude of 10 times of the normal feed concentration and pulse durations as long as 7 hours.

Nitschke studied the effect of glycols on activated sludge wastewater treatment plants. He found that avoiding shock loads and maintaining an adapted activated sludge at the WWTP, especially at a low wastewater temperatures, would ensure that BOD effluent values do not exceed critical limits (Nitschke et al.1996). To maintain a sufficient degree of biodegradation, it is necessary to adapt the activated sludge to ADF during a several day acclimation period. The activated sludge has to be maintained in its acclimated state to glycols as long as possible during periods of no deicing at the airport (Nitschke et al.1996). In other words, the discharge of the retention basin should be stretched as long as possible. Completely mixed activated-sludge processes, because of their mixing, provide a great deal of dilution of the incoming waste material. When toxic materials are introduced into the influent stream, the dilution capacity helps prevent process upset (Schroeder 1977). The CFSTR process is more stable than nominal plug-flow processes.

The Salt Lake City Wastewater Reclamation Plant experienced biological growth problems in its trickling filters and a drop in soluble BOD removal efficiencies as glycol wastewater discharges to the plant increased (Krumsick et al. 1994). The deicing wastewater, during the winter months, increased the POTW's soluble BOD loading by 20% (Krumsick et al. 1994). Tests were conducted on the pilot scale to identify the optimal system for handling high strength glycol

wastewater. The conclusions were that a trickling filter with high-density plastic media reduced soluble BOD more effectively than did a trickling filter with medium-density plastic or rock media (Krumsick et al.1994). Operating from 13 to 18 degrees Celsius, the high-density plastic media obtained over 90% BOD removal while medium-density plastic media and rock media achieved about 75% removal (Krumsick et al.1994). Up to 20 percent glycol deicing wastewater mixtures with municipal wastewaters were successfully treated with the trickling filter process (Krumsick et al.1994).

13.3.2 ANAEROBIC TREATMENT PERFORMANCE

The EFX Fluidized Bed Reactor provides removal efficiencies of 92% for an influent propylene glycol concentration of 2,500 mg/L (EFX 1998). The above removal efficiency can be achieved with an applied organic loading rate less than or equal to 4.75 kg COD/m³-d (0.89 lb COD/ ft³-d) and an influent COD less than 4,800 mg/L with an effluent COD of 400 mg/L. Typical performance of an anaerobic EFX system can be seen in Table 6.

Table 6: Comparison of Performance of ADF Treatment by a POTW, EFX Anaerobic Treatment and AnAerobic MFT Treatment.

Source of Data: Cummings 1996, Speece 1998

Parameter	POTW	EFX Anaerobic Treatment	AnAerobic MFT Treatment
COD Loading (g-COD/L-d)	0.3 – 0.6	4.75	10 - 20
COD Removal Efficiency, %	99	92%	95
Energy Production (therms/1000-lb-COD)	0	13	56
Sludge Production (lb-TS/lb-COD)	0.4 – 0.6	0.04 - 0.06	0.023
Energy Required (kw-hr/lb-COD)	1	0.1	0.1
Operational Temperature (°F)	varies	90	95

The anaerobic bioreactor produces biogas that is approximately 70% methane and 30% CO₂ (Harrison 1998). The CO₂ can be removed and the methane compressed and used as a heater fuel to increase the temperature of the water in the bioreactor (Harrison 1998). This helps increase the decomposition rate of the ADF since the microorganisms work better at higher water temperatures. Anaerobic systems produce less biomass than aerobic systems, specifically about 10% of the sludge production of aerobic processes.

AnAerobics performed a pilot study that successfully demonstrated consistent, high rate, and highly efficient conversion of propylene glycol at COD loading rates in excess of 1.0 lbs COD/ft³ d. Figure 6 compares the performance of AnAerobic Inc. and EFX's anaerobic treatment systems. Methane production rates

were in excess of 6 volumes per volume of bed per day (v/v-d) and effluent COD concentrations less than 600 mg/L (Influent COD 15,000 mg/L). The AnAerobic mobilized film technology achieves COD removals of 95% (Cummings 1995). Pilot tests showed the process efficiency increased as temperatures increased from 4 degrees C to 60 degrees C. Importantly, the ADF influent COD concentration was between 5000 and 15000 mg/L (Cummings 1995). AnAerobics diluted the ADF wastewater with water prior to treatment to decrease the influent COD. The issue is that this removal is achieved after the ADF is diluted to 5,000 mg/L with noncontaminated stormwater (Cummings 1995). Effluent COD concentrations are less than 600 mg/L (Cummings 1995). Therefore, AnAerobics Inc. claims that when high quality wastewater treatment is required, the technology must be followed by an aerobic treatment system to polish the MFT effluent.

Comparing the EFX and AnAerobic Inc. MFT anaerobic treatment systems, both have high performance results. The AnAerobic MFT system can accept higher COD loads in order to achieve a higher efficiency than the EFX system (10-20 vs. 4.75 g-COD/L-d). The AnAerobic MFT system produces more energy (56 vs. 13 therms/1000-lb-COD) and less sludge (0.023 vs. 0.04 lb-TS/lb-COD) than the EFX system but the EFX system operates at a lower temperature than the AnAerobic MFT system (90 vs. 95 °F).

13.3.3 RECYCLING PERFORMANCE

To even consider recycling spent ADF, the ADF/water mixture must be at least 25% ADF (Harrison 1998). Most spent ADF and water mixtures have ADF concentrations less than 10% (Cummings 1995). With an influent glycol concentration of 15 – 28%, the recycling system can produce an effluent stream with an average glycol content of between 55.1 – 98.5% (US EPA 1995). The main process in glycol recovery is distillation. Distillation has been successfully used either singly or in combination with condensation, adsorption, and absorption for the recovery of organic solvents. Product with high purity (>90%) can be obtained by two-stage distillation. According to personal conversation with Mr. Jim Hamilton of Glycol Specialists Inc, GSI owns and operates a glycol recovery system in Denver CO. GSI treats about 25% of the deicing fluid volume generated (Hamilton 2000). DIA's tanks have a total capacity of 160,000 gallons. It is estimated that a heavy storm generates 30,000 to 100,000 gallons of contaminated runoff (GSI 1995). Typically, the contaminated runoff from DIA contains 28% glycol. The recovery system produced an effluent stream with an average glycol content of 98.5% with the remaining portion being water (GSI 1995).

13.4 MANAGEMENT AND MAINTENANCE

13.4.1 AEROBIC TREATMENT MANAGEMENT AND MAINTENANCE

Aerobic systems involve extensive management and maintenance requirements. Due to the large sludge production of an aerobic system, sometimes 90% greater than that of anaerobic treatment, aerobic systems require extensive materials management. This requires addition personnel to manage and maintain the system.

Sending spent ADF directly to a wastewater treatment plant stresses the treatment abilities of the plant. Most wastewater treatment plants operate aerobically and are designed to treat low strength domestic wastewater. The high BOD levels of deicing fluid can overload an aerobic processes. Therefore, additional management and maintenance requirements are incurred to protect the plants operation.

13.4.2 ANAEROBIC TREATMENT MANAGEMENT AND MAINTENANCE

Anaerobic systems at airports are usually operated in the wintertime. To put the system online, management and maintenance is necessary. After the process stabilizes, low operator attention is necessary (Speece 1998).

13.4.3 RECYCLING MANAGEMENT AND MAINTENANCE

Recycling processes based on distillation tend to be complex operationally due to the thermodynamics behind the process (US EPA 1995). Due to the complexity and frequent start-ups and shutdowns, recycling units have high management and maintenance requirements.

14.0 CONCLUSIONS

A summary of the evaluation of the alternatives using the indicated criteria (Chapter 11) can be seen in Table 7 and 8.

Table 7: Summary Evaluation of the Storage Alternatives.

	In-Line Storage	Off-Line Storage
Performance (% removal)	none	minimal
Performance (flow attenuation)	good	good
Meets Regulatory Requirements?	yes	possibly
Management/ Maintenance	low	low

The storage performance was evaluated by comparing percent organic removal and flow attenuation. In terms of percent removal, the off-line option has the ability to remove a small percentage of organics through the installation of an aeration system. The in-line system does not provide organic loading removal. Both systems provide flow attenuation. The in-line system, if installed correctly, meets regulatory requirements. The off-line system must be careful with meeting placement regulations at airports due to the attraction of birds to surface water. Management and maintenance is required for both in-line and off-line storage. Systems should be inspected to remove debris within 24 hours after a significant rainfall or snowmelt since heavy storms may clog the drainage system. For off-line

storage, aesthetics are extremely important and therefore it is wise to properly maintain the area around and in the off-line storage facility. Cost was not considered in the evaluation.

Table 8: Summary Evaluation of the Treatment Alternatives.

	Aerobic Treatment	Anaerobic Treatment: EFX Systems	Anaerobic Treatment: AnAerobic Inc.	Recycling
Estimated Cost (\$/year)	51,000	150,000	75,000	105,000
Performance (% removal)	Variable	92	95	55.1-98.5
Meets Regulatory Requirements?	Possibly	Yes	Yes	Yes
Management/Maintenance	High	Low	Low	High

Table 8 is a summary of the evaluation of the treatment alternatives using the criteria of cost, performance, regulatory requirements and management and maintenance. The cost includes capital, operations, and maintenance costs. The cost assumes 300,000 gallons of ADF contaminated stormwater must be treated each year for twenty years. The aerobic option of discharging the contaminated stormwater to a WWTP or POTW is the most cost feasible. The cost to discharge the contaminated stormwater to a POTW prior to treatment, based on seventeen cents per gallon of glycol-contaminated stormwater, is estimated to be \$51,000/yr. An anaerobic fluidized bed system large enough to accommodate the contaminated stormwater costs about \$150,000 annually (Civil Engineer 1999). Similarly, an

anaerobic on-site treatment system manufactured by AnAerobics Inc. costs about \$75,000 per year. Assuming an annual ADF usage of 30,000 gallons, a recycling unit costs about \$105,000 per year.

All of the treatment options have the ability to comply with NPDES regulations. On-site anaerobic treatment is a pretreatment option that can be used prior to sending the stormwater to a POTW or base WWTP. It cannot be assumed that on-site anaerobic treatment is sufficient for the stormwater to be discharged into lakes and streams. It is important to note that when an airport discharges spent ADF directly to a POTW, the airport increases the risk of violating the POTW discharge permits. The airport is “gambling” with the hope that the spent ADF does not shock the POTW’s system. This makes flow attenuation extremely important. Finally, despite the effectiveness of a recycling system, there will always be a discharge of some waste from recycling to a POTW or other receptor.

In terms of performance, anaerobic treatment provides the highest overall removal efficiency. The EFX anaerobic treatment system provides removal efficiencies of 92% (EFX 1998). The AnAerobics comparable treatment system achieves removal efficiencies of 95% (AnAerobic 1999). Table 6 showed a detailed comparison of performance of ADF treatment by a POTW, EFX Anaerobic treatment and AnAerobic MFT treatment.

The COD loading of the treatment options is important in determining the efficiencies. The loading of the EFX system is 4.75 g-COD/L-d to achieve 92%

removal. The AnAerobic EFX system has a loading of 10-20 g-COD/L-d to achieve 95% removal. Aerobic treatment systems for ADF provide variable removal efficiencies depending on the type of biological system available and the loading at the POTW or WWTP. Finally, with an influent glycol concentration of 15 – 28%, the recycling system can produce an effluent stream with an average glycol content of between 55.1 – 98.5% (US EPA 1995).

The management and maintenance for anaerobic systems are lower than for aerobic systems. Management and maintenance is necessary to put an anaerobic system online but, after process stability, low operator attention is necessary (Speece 1998). Aerobic systems require more attention than anaerobic systems due to higher sludge production and due to the required aeration and mixing components. Due to the complexity and frequent start-ups and shutdowns, recycling units have high management and maintenance requirements.

15.0 RECOMMENDATIONS

The United States Air Force Center For Environmental Excellence (AFCEE) requested an analysis of aircraft deicing fluid (ADF) management options available for the treatment and disposal of ADF contaminated stormwater. Therefore, several airplane deicing fluid storage and treatment options were evaluated. The critical issue was finding a way to store the ADF contaminated runoff and dispose of the collected waste in order to ensure that flight operations will not be restricted. In order to evaluate the effectiveness of deicing treatment options, many criteria were considered. Meeting EPA regulations coupled with a minimum cost solution were the major criteria. Other criteria included meeting National Pollutant Discharge Elimination System Permit requirements and management and maintenance requirements.

After careful analysis of the treatment options, the following conclusions can be made. The implementation of a flow attenuation facility with the controlled discharge to a WWTP or POTW appears to be the most effective management option based on the criteria for ADF contaminated stormwater.

In terms of cost, the aerobic option appears to be the most cost feasible, with annual costs of about \$51,000 to treat 300,000 gallons of ADF contaminated stormwater at an Air Force base. This cost includes capital, operations and maintenance costs assuming a twenty-year operating life. Additional management and maintenance at the POTW or WWTP will be necessary due the increased stress

placed on the POTW due to the contaminated stormwater. The additional cost was included in the annual cost estimates.

With a properly designed equalization basin and subsequent discharge to a POTW or WWTP, it is possible for an Air Force Base to consistently meet regulation requirements along with performance requirements. For example, a WWTP may impose peak concentration limits and a total annual receiving limit for ADF. A flow attenuation facility would be able to accommodate these limits to prevent notices of violation of the discharge permits. Most POTWs will not accept waste with a glycol concentration greater than 5% (Strong-Gunderson et al. 1995). Most untreated ADF contaminated stormwater has a glycol concentration greater than 10%. Therefore, flow attenuation is necessary. A retention basin can collect large volumes of glycol wastes from pavement surface runoff. The basin must be large enough to "handle surface runoffs for winter months noting the decreased microbial activity during the winter season which is needed for biodegradation, plus additional capacity for runoff during thawing periods" (Federal Register 1995).

A variety of operational problems attributed to ADF waste streams have been reported at several POTWs (Jank et al. 1974, and Krumsick et al. 1994). To prevent operational problems, it is important to understand the treatment processes available at the WWTP. The plant's treatment processes will help to determine the peak concentration limits and the total annual receiving limit for ADF. However,

individual airport – specific conditions and economic considerations will be the defining factors in the suitability of ADF recovery.

APPENDIX A

Regulations

When the FAA increased its deicing requirements, as a result of the clean aircraft concept, the EPA increased pressure for storm water management (Mericas 1994). Storm water from urban runoff and storm sewers is the second leading source of water quality impairment for lakes and estuaries and the third for rivers (US EPA 1998). ADF runoff contributes to this load. Therefore, storm water regulations apply to airports and specifically ADF runoff. ADF stormwater runoff is considered a discharge "associated with industrial activity" (Moffa 1996). "Stormwater" is defined as "stormwater runoff, snow melt runoff, and surface runoff and drainage" (US EPA 1993). "Stormwater discharges associated with industrial activity" is defined as stormwater discharge from one of eleven categories of industrial activity specified in 40 CFR. Deicing operations fall into category eight which includes transportation facilities classified as Standard Industrial Classification 40-45 that have vehicle maintenance shops, equipment cleaning operations or airport deicing operations (US EPA 1993).

Storm Water Regulation

The ultimate goal of storm water regulation is pollution prevention. In 1990, the EPA promulgated storm water regulations, requiring airports and any other business with storm water runoff to submit an NPDES permit application (Sills and

Blakeslee 1991). The regulation has four different NPDES application processes: an individual permit application, a multi-sector general permit application, and two general permit applications (PROACT 1995). The individual permit application covers a single installation, often requires monitoring and is usually more expensive to implement (PROACT 1995). An individual permit is necessary, for example, if the discharger may potentially violate a water quality standard, pollutes the water significantly, or endanger wetlands (PROACT 1995). Multi-sector permits are industry-specific. An industry must comply with all the requirements in the permit sections that cover its operations (PROACT 1995). One type of general permit deals with construction sites while the other applies to industrial activities. The most important point to remember is that airports must apply for a storm water discharge permit for locations where deicing chemicals are applied (US EPA 1992). This includes runways, taxiways, and ramps.

Air Force Storm Water Regulations

Air Force Instructions (AFI) outline the Air Force requirements for storm water NPDES permitting. According to AFI 32-7041, airport deicing operations require storm water NPDES permits and require the development of a Storm Water Pollution Prevention Plan including Best Management Practices. Storm Water Pollution Prevention Plans (SWP3) consist of steps to identify potential sources of pollution or contamination on an installation and carry out actions which prevent or control the pollution of storm water. The steps are planning and organizing,

assessment, Best Management Practices (BMP) identification, implementation, and evaluation/monitoring (PROACT 1995). Each step is outlined in Table A-1.

Table A-1: Key Aspects of Each Step in the Storm Water Pollution Prevention Strategy

Source: PROACT 1995

Storm Water Pollution Prevention Steps	Key Aspects of each Step
Planning and organizing	Establish a pollution prevention team Review existing environmental management plans
Assessment	Evaluate sources of potential contamination to storm water
Best Management Practice (BMP) identification	Identify where good housekeeping practices, preventative maintenance, visual inspections, spill prevention, and runoff management can be improved
Implementation	Establish a schedule for implementation Assign implementation responsibilities Ensure management approval Employee training
Evaluation/Monitoring	Annual site compliance evaluations Record keeping and reporting procedures Amend the plan if necessary

Air Force ADF Regulation

The Air Force only approves the use and purchase of propylene glycol-based deicing fluids. The type of aircraft deicing fluid most commonly used by the air force is military specification Mil-A-8243D Type I.

Air Force Pollution Prevention Strategy

According to Air Force Environmental Policy, “the Air Force has a vision for Environment, Safety, and Occupational Health (ESOH)” (Ryan and Peters 1999). The three ESOH principles include sustain readiness, be a good neighbor, and leverage resources. According to General Michael E. Ryan, chief of staff of the USAF, “the margin of success today and in the future might well depend on the understanding by all that every aspect of our mission and every system has human and environmental impacts” (Ryan and Peters 1999).

Air Force Instruction 32-1002 (AFI) provides guidance on snow and ice control for Air Force personnel. According to AFI 32-1002, every Air Force Base with more than six inches average annual snowfall must maintain a Snow and Ice Control Plan (S&ICP). As seen in Appendix C, this includes the majority of AFBs evaluated in this report. The S&ICP committee has two key members, the civil and environmental engineers for the base. The base civil engineer is to coordinate installation snow and ice control activities while the environmental engineer is to “provide storm water management to minimize potential impact of aircraft . . . deicing chemicals. Programs for Environmental Compliance (EC) projects will contain, control, and potentially treat SW runoff” (AFI 1994). The Instruction goes on to say that the environmental person “ensures guidance on P2/BMPs is disseminated effectively to personnel conducting airfield deicing” (AFI 1994). Also, the environmental flight must “perform annual evaluation of implementation

status and effectiveness of P2/BMPs and recommend to the S&ICC (snow and ice control) actions to improve effectiveness” (AFI 1994). According to Maj Jeff Cornell (2000), bioenvironmental engineer at the Air Force Center for Environmental Excellence, the record keeping for snow and ice control in the Air Force is not accurate at many bases. He feels that the lack of record keeping stems from a lack of training of snow and ice control personnel. For example, AFI 32-1002 states that each AFB is responsible for tracking the consumption of deicing chemicals and abrasives used on their airfields. The following information is required when collecting this data; each type of deicer and/or abrasive used, quantity, unit of issue, unit price, method of procurement, total inches of snowfall for the past winter, total number of ice events/storms, total number of sorties flown. Appendix C shows the information that is available on deicing procedures for various AFBs. The above “required information” is not readily available, according to the research for this report.

The Air Force, along with the EPA, encourages the implementation of Best Management Practices (BMPs). Although the ultimate goal of the Air Force is zero discharge of deicing chemicals to surface waters, pollution prevention (P2) and BMP’s can be implemented quickly and relatively inexpensively to achieve reduction in deicing chemical waste discharges to the environment until structural solutions may be implemented (Nault et al. 1997). BMPs for deicing activities, for example, include reducing the number of aircraft exposed to icing conditions that require

deicing through strategically parking the aircraft, removing snow using brooms, ropes, and squeegees prior to deicing fluid use, and training personnel on how to prevent the excessive use of ADF. "Common sense" BMPs can be easily and cost effectively implemented in order to minimize spent ADF generation. P2/BMPs for controlling runoff of aircraft deicing/anti-icing may include: blocking or closing storm sewer grates during dry weather deicing, conducting aircraft deicing operations in areas where runoff can easily be contained (PROACT 1998).

APPENDIX B

Emerging Technology: No Chemical Use

One technique for reducing chemical use in deicing is based on heat from infrared wavelengths. Figure B-1 shows an aircraft being deiced using the InfraTek technology.

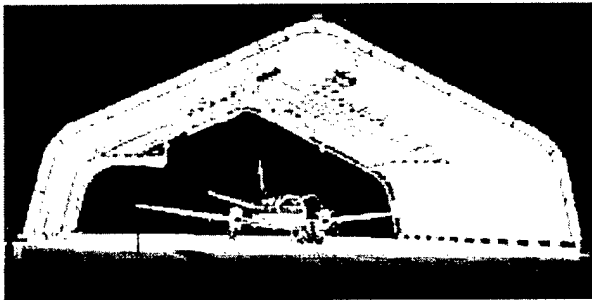


Figure B-1: Aircraft Deicing with the InfraTek System
Source: InfraTek 2000

The procedure works as follows: the aircraft, after loading passengers, travels from a gate to a hanger like structure. Immediately before takeoff, the plane pulls into the structure outfitted with the infrared energy process units and parks for approximately six minutes while the deicing takes place. Some chemicals may still be used for anti-icing but this system would drastically reduce the overall amount of glycols used (Natural Resources Defense Council 1996). Capital costs range from 1 to 1.7 million dollars while O&M costs about \$100-200 per hour for gas and electricity (Radiant 2000). Using conventional glycol sprays, airline currently pay up to \$2,500 to deice one aircraft (Natural Resources Defense Council 1996). Seele

estimates a cost of approximately \$250/plane to deice aircraft using InfraTek. The FAA successfully demonstrated the InfraTek technology at Rochester International Airport when the system effectively deiced a FAA Boeing 727 within 6 minutes (FAA 1997). Snow was piled two inches on the aircraft (Seele 2000). InfraTek technology is also in use at Rhinelander Airport in Wisconsin. Rhinelander decreased their ADF usage by 85% (Seele 2000). An InfraTek deicing system was installed January of 2000 at Newark International Airport in New York (Seele 2000). The FAA has approved use of this system as part of the deicing regime (FAA 1997).

APPENDIX C

Appendix C is a spreadsheet of Air Force Base and commercial airport information concerning deicing operations. The information was obtained from Ecology and the Environment, the National Defense Center for Environmental Excellence, journal articles and personal interviews. The column entitled "NPDES Stormwater Permit" is based on a yes/no answer to whether the base or airport has a permit for deicing operations. The next column explains what chemical is used for deicing and the chemical to water mixture. The following column is the average annual glycol use at each base or airport in gallons of glycol per year. The column entitled "monitoring program" explains what the airport is currently doing to manage spent deicing fluid. The next column shows the sanitary discharges that are available to the base or commercial airport. The options include POTWs, on base WWTPs, and industrial WWTPs. The final two columns give the average annual snowfall in inches and the mean January air temperature in degrees Fahrenheit at the particular base.

Appendix C: Base and Commercial airport data

Source of data: Ecologynv 1997, NDCEE 1996, Backer et al. 1994, Conetta et al. 1997

Base	NPDES Stormwater Permit	Chemical	Average Annual Usage (gal)	Monitoring program	Drainage	Sanitary Sewer discharge available (not necessarily being used)	Average Annual Snowfall (in)	Mean January Air Temp (F)	
Ellsworth AFB, SD	Yes	Propylene glycol, 60/40 mix	15,143	Outfall - BOD5, weekly during spring snow melt	To surface water outfall through a retention pond with aeration unit	POTW	38.9	20.8	
Whiteman AFB, MO	Yes	Propylene glycol, 60/40 mix	2500	Outfall - BOD5, COD, DO quarterly	Deicing pad has two-way valve inlet to IWWTP or storm	IWWTP to sanitary sewer to base WWTP	18.6	29	
Offutt AFB, NE	No	Propylene glycol, 50/50 mix	20,000	None	Deicing pad has three-way valve inlets to City of Omaha POTW, storage tanks or storm	POTW	32.2	20.2	
Little Rock AFB, AR	Yes	Propylene glycol, 30/70 mix	4500	None	To surface water outfall	POTW	5.3	39.5	
Minot AFB, ND	Yes	Propylene glycol, 60/40 mix	15,300	Outfall- BOD5 COD	Drains to storm sewer or into drainage ditches and then to surface water outfall	base WWTP	39.1	6.2	
Mountain Home AFB, ID	Yes	Propylene glycol, adjusted mix	15,000	None	To on base storm drain system, open channels	base WWTP	13.3	29.4	
Pope AFB, NC	no	Propylene glycol, 60/40 mix	35,000	Outfall - nitrate/nitrite quarterly	To storm drain system and surface water		3.6	41.4	
Seymour Johnson AFB, NC	no	Propylene glycol, adjusted mix	1,100	None	To storm drain system and surface water		5.1	41.5	

Appendix C: Base and Commercial airport data
Source of data: Ecology 1997, NDCFF 1996, Backer et al. 1994, Conetta et al. 1997

Source of data: Ecologyv 1997, NDC EE 1996, Backer et al. 1994, Conetta et al. 1997

[illegible]

Appendix C: Base and Commercial airport data

Source of data: EcologyNY 1997, NDCOE 1996, Backer et al. 1994, Conetta et al. 1997

Airport	NPDES Stormwater Permit	Chemical	Average Annual Usage (gal)	Monitoring program	Drainage	Sanitary Sewer discharge available (not necessarily being used)	Average Annual Snowfall (in)	Mean January Air Temp (F)	
Albany International Airport Albany, NY	yes	propylene glycol, 50/50 mix	100000	BOD5, COD etc	Recycle @ PG > 25% concentration, or spray irrigation, or retention basin to anaerobic GAC to POTW; 1ppm limit on Maximum Allowable PG				
Westchester County Airport, NY ⁴	yes	propylene glycol, 50/50 mix	16435 ; Average # of deicing days per year :50		two valve system to allow drainage to sanitary sewer during deicing periods (flow restriction valve to limit flow to prevent shock loading) and storm sewer to surface water during non-deicing periods				
Denver International Airport	yes	propylene glycol, 50/50 mix	1million	BOD5, COD etc	detention basin to surface water in detention basin to sanitary sewer to wwtp or detention basin to recycling: concentration dependent	WWTP max load = 5400 kg/day			

REFERENCES

- Air Force Instruction 32-1045. 1994. "Snow and Ice Control." March 7, 1994.
- Air Force Instruction 32-7041. 1994. "Water Quality Compliance." May 13, 1994.
- AnAerobics Inc. 2000. "AnAerobics Mobilized Film Technology." Available at: www.anaerobics.com/tech.html. Accessed on April 1, 2000.
- Backer, D.S., Smith, D., Habben, C.E. 1994. "Deicing Dilemma." *Civil Engineering*. 64: 55-59.
- Barnes, D. 1995. "Anaerobic Wastewater Treatment Systems." *Modern Techniques in Water and Wastewater Treatment*. Kolarik, L.O., Priestley, A.J. CSIRO Australia. 91-97.
- Bausmith, D. S., Neufeld, R. D. 1996. "Land treatment of aircraft deicing fluids." WEFTEC '96, Dallas, TX.
- Boluk, Y., Levesque, P. 1990. "Aircraft Deicing Fluid Recovery: Concerns About the Quality Of Recycled Glycol for Use in Various Applications." Toronto, Technology Department, Union Carbide Canada Limited.
- Cancilla, D. A., Holtkamp, A. 1997. "Isolation and Characterization of MicrotoxTM Active Components from Aircraft Deicing/Anti-icing Fluids." *Environmental Toxicology and Chemistry*.
- Cheremisinoff, P.N. 1995. *Handbook of Water and Wastewater Treatment Technology*. Marcel Dekker Inc., New York.
- Chesterfield, B.P. 1996. "KC-10 Icing, Deicing and Anti-Icing Safety of Flight Considerations." Oklahoma City Air Logistics Center, OK.
- Civil Engineering. June 1999. "Thermal Deicing System Makes Waves at Airports." 12(10).
- Civil Engineering. July 1999. "Airport Facility Treats Deicing Runoff." 70.
- Conetta, A., Bracchitta, R., Sherrer, P. Autumn 1997. "Storm Water Management and Control of Aircraft Deicing Runoff at Westchester County Airport." *Environmental Regulation and Permitting* : 37-41.

Cornell, J. S., Pillard, A. 1998. "Chemical Components of Aircraft Deicer Fluid: How They Affect Propylene Glycol Degradation Rates and Deicing Waste Stream Toxicity." Water Environment Federation Technical Conference, Orlando FL, *In Press*.

Cornell, J.S. March 2000. Air Force Bioenvironmental Engineer. Personal Interview.

Cox, D. P. 1978. "The Biodegradation of Polyethylene Glycols." *Advanced Applied Microbiology*. 23: 173-194.

Cross Talk. May 1996. "Exploring Available De-Icing Technologies." (24). Available at: <http://www.afcee.brooks.af.mil/ed24.htm>. Accessed Jan 11, 2000.

Cummings, R.J. 1995. "Treatment of Airport De-icing Fluids with the Anaerobic Mobilized Film Technology." *Aircraft Airfield Deicing Conf. And Expo, Washington D.C.*

Darlington, C., Kennedy, K.J. 1998. "Biodegradation of Aircraft Deicing Fluid in an Upflow Anaerobic Sludge Blanket (USAB) Reactor." *Environ. Sci. Health*. A33(3), 339-351.

Downs, W.R. 1968. "Chemically Induced Ignition in Aircraft and Spacecraft Electrical Circuitry by Glycol Water Solutions." Technical Report. NASA Manned Spacecraft Center Huston, Washington, D.C.

EA-Engineering Science and Technology. 1996. "Comparative Toxicity and Environmental Impacts of Ethylene Glycol and Propylene Glycol: A Review." Silver Spring, MD, EA Engineering, Science, and Technology.

Ecology and Environment, Inc. February 1997. "Final Site Visit Plan Deicing/Anti-Icing Operations Compliance Evaluation at Various ACC Bases." F44650-94-D0006.

EFX Systems, Inc. 1996. "Deicing Fluid Treatment: Fluidized Bed Bioreactors." EFX-96/AN01. Westbury, NY.

EFX Systems, Inc. 1999. "Design and Operation of a Full-scale Anaerobic Fluidized Bed Reactor at the Albany County Airport." Albany County Airport Authority, Albany, NY.

Ellis, T. G., Smets, B. F. et al. 1998. "Effect of Simultaneous Biodegradation of Multiple Substrates on the Extant Biodegradation Kinetics of Individual Substrates." *Water Environ. Res.* 70(1): 27-38.

ENSR Engineering. 1993. "Evaluation of the biotic communities and chemistry of the water and sediments in sand creek near Stapleton International Airport." Denver, CO, Stapleton International Airport Authority.

Evans, G.S. Oct 1996. "Evolution of Aircraft Deicing Facilities in Denver Colorado." *Proc. Instn Civ.* 117: 216-221.

Evans, W. H., David, E.J. 1973. "Biodegradation of Mono-, Di- and Triethylene Glycols in River Waters under Controlled Laboratory Conditions." *Water Research.* 8: 97-100.

Federal Aviation Administration. April 1997. "FAA Approves New Infrared Deicing Technology for Aircraft." *FAA News*, Washington, D.C.

Federal Aviation Administration. Jan 2000. "FAA Icing Rule Change." *AIRWise NEWS*. Available at: <http://news.airwise.com/stories/99/07.html>. Accessed on Jan 24, 2000.

Federal Register. Sept 29, 1995. "Aircraft Deicing/Anti-Icing." 60(189).

Fisher, D. J., Knott, M. H. et al. 1995. "The Acute Whole Effluent Toxicity of Storm Water From an International Airport." *Environmental Toxicology and Chemistry* 14(6): 1103-1111.

Flatham, P. E., Jerger, D. E. et al. 1989. "Remediation of Contaminated Groundwater Using Biological Techniques." *Ground Water Monitoring Review.* 105-119.

Glycol Specialists, Inc. (GSI). 1995. "Case Studies and Evaluation of Current Status of Applications." USEPA Emerging Technology Report: Preliminary Status of Airplane Deicing Fluid Recovery Systems. A10-A12.

Gunderson, J.M., Wheelis, S., Carroll, S.L., Waltz, M.D., Palumbo, A.V. 1996. "Degradation of High Concentrations of Glycols, Antifreeze, and Deicing Fluids." *Microbial Processes for Bioremediation.* 265-270.

Haines, J. R., Alexander, M. 1975. "Microbial Degradation of Polyethylene Glycols." *Applied Microbiology.* 29(5): 621-625.

- Hamilton, J. March 2000. Glycol Specialists, Inc. Personal Interview
- Harrison, P.B. 1998. "Albany Deicing Meeting on Airline Perspective on Deicing." American Airlines.
- Hartwell, S.I., Jordahl, D.M. 1995. "Toxicity of Aircraft Deicer and Anti-icer Solutions to Aquatic Organisms." *Environmental Toxicology and Chemistry*. 14(8), 1375-1386.
- Hickey, R. 1998. "Design and Operation of a Full-Scale Anaerobic Fluidized Bed Reactor at the Albany County Airport." Albany NY.
- Higgins, T.E. 1995. *Pollution Prevention Handbook*. Lewis Publishers, FL.
- Hobson, P.N., Wheatley, A.D. 1993. *Anaerobic Digestion: Modern Theory and Practice*. Elsevier Applied Science, London.
- Holladay, D.W., Hancher, C.W., Scott, C.D. 1978. "Biodegradation of Phenolic Waste Liquors in Stirred-Tank, Packed-bed, and Fluidized-bed Bioreactors." *J. Water Pollution Control Federation*, 50(11), 2573-2589.
- Iachetta, S. Jan 29, 1998. "Albany County Airport De-icing Conference Presentation." *PG Toxicological Summary*. Albany, NY.
- Jank, B.E.; Guo, H.M.; and Cairns, V.W. 1974. Activated Sludge Treatment of Airport Wastewater Containing Aircraft Deicing Fluids. *Water Resources*. 8, 875-880.
- Klecka, G. M., Carpenter, C. L. et al. 1993. "Biodegradation of Aircraft Deicing Fluids in Soil at Low Temperatures." *Ecotoxicology and Environmental Safety* 25: 280-295.
- Kolarik, L.O., Priestly, A.J. 1995. *Modern Techniques in Water and Wastewater Treatment*. CSIRO, Australia.
- Komisar, S., Weinert, C. 1998. "Start-up Operation of the Pilot Scale Anaerobic Fluidized Bed Reactor at ACA." Department of Environmental and Energy Engineering, Polytechnic Institute. Albany NY.
- Kotker, D. 2000. "New Deicing/ Anti-Icing Fluids." Available from: <http://www.boeing.com/commercial/aeromagazine>. Accessed 2000 March 6.

- Kruger, E.L., Anderson, T.A., Coats, J.R. 1995. "Phytoremediation of Soil and Water Contaminants." ACS Symposium Series, American Chemical Society, Washington D.C.
- Krumsick, T.A.; Daigger, G.T.; and Farmer, W.W. 1994. "Glycol Wastewater Treatability Study." *Proc. Water Environ. Fed. 67th Annul. Conf. Exposition*, Alexandria, Virginia.
- Liu, P.K.T. Sept 1998. "On-Site Recovery of Glycols from Airport Deicing Fluid Using Polymeric /Ceramic Composite Membranes." Media Process Technology, Inc., Available from : http://es.epa.gov/ncercqa_abstracts/sbir/96/water2/ (5 January 2000).
- Lokke, H. 1983. "Leaching of Ethylene Glycol and Ethanol in Subsoils." *Water, Air, and Soil Pollution* 22: 373-387.
- Lubbers, L. 1993. "Laboratory and Field Studies of the Toxicity of Aircraft Deicing Fluids." SAE Aircraft Ground Deicing Conference, Salt Lake City, UT, Maryland Department of the Environment Tidewater Administration.
- MacDonald, D.D., Cuthbert, I.D., Outridge, P.M. 1992. "Canadian Environmental Quality Guidelines for Three Glycols Used in Aircraft Deicing/ Anti-icing Fluids." EcoHealth Branch, Environment Canada, Ottawa, Ontario, Canada.
- Mayer, F.L., Eilersieck, M.R., 1986. "Manual of Acute Toxicity: Interpretation and Data Base for 410 Chemicals and 66 Species of Freshwater Animals." Resource Publication 160. U.S. Fish and Wildlife Service, Washington, D.C.
- Massardo, A.F. 1996. "Experimental Investigation of a New and Energy-Saving Nacelle Anti-Ice System." *Journal of Aircraft*. 33(6), 1033-1039.
- McCarty, B.D. 1996. "Technology Assessment Requirements Analysis." Human Systems Center Development Planning Directorate. Available from: <http://www.afcee.brooks.af.mil/eq/p2cd/factshee>. Accessed Jan 11, 2000.
- McGahey, Bower. 1992. "Biodegradation of Ethylene Glycol in Simulated Subsurface Environments." *Water Science and Technology* 26(1-2): 41-49.
- Means, J., Anderson, S. J. 1981. "Comparison of Five Different Methods for Measuring Biodegradability in Aqueous Environments." *Water, Air, and Soil Pollution*(16): 301-315.

- McLean, K.M. 1995. "High-Rate Anaerobic Digestion : An Overview." *Modern Techniques in Water and Wastewater Treatment*. Kolarik, L.O., Priestley, A.J. CSIRO Australia. 133-140.
- Mericas, D., Wagoner, B. 1994. "Balancing Safety." *Wat. Env. Tech.* 6(12), 38-42.
- Metcalf and Eddy, I. 1991) *Wastewater Engineering: Treatment, Disposal, and Reuse*. New York, McGraw-Hill, Inc.
- Miller, L. M. 1979. "Investigation of Selected Potential Environmental Contaminants: Ethylene Glycol, Propylene Glycol and Butylene Glycols." Washington DC, US EPA.
- Moffa, P.E. 1996. *The Control and Treatment of Industrial and Municipal Stormwater*. Van Norstrand Reinhold, NY.
- Mynczywor, S. G. 1995. "Exploring Available Deicing Technologies." Maxwell AFB, Gunter Annex, AL, US Air Force Logistics Management Agency.
- National Defense Center for Environmental Excellence. Aug 1996. "Deicing/Anti-icing Technologies and Case Studies." Concurrent Technologies Corporation, PA.
- Natural Resources Defense Council. Oct 1996. "Flying Off Course: Environmental Impacts of America's Airports." NRDC. Washington, D.C.
- Nault, G., Francis, D., Fronapfel, P., Fields, M.K., Malinowski, P., 1997. "Aircraft and Airfield Deicing/Anti-icing Operations Pollution Prevention (P2)/ Best Management Practices (BMPs)." U.S. Air Force Air Combat Command Environmental Training symposium, Houston, Texas.
- Nitschke, L., Wagner, H., Metzner, G., Wilk, A., Huber, L. 1996 "Biological Treatment of Waste Water Containing Glycol From Deicing Agents." *Water Resources*, 30(3), 644-648.
- Noll, K.E., Schmidt, C., Haas, C.N., Kodukula, P. 1985. *Industrial Waste Management*. Lewis Publishers, Inc. MI.
- Northwest Airlines. 2000. Photograph of Deicing. Available at: www.nwa.com. Accessed January 6, 2000.

Oak Ridge Centers for Manufacturing Technology. 2000. "Biodegradation of Glycol at Airports and Natural Gas Pumping Stations." Available from: <http://www.ornl.gov/orcmt/capabilities/dtin347.html>. Accessed Jan 11, 2000.

Owens, R. 2000. "EFX Systems Inc. Core Technology." Available at <http://www.clever.net/efxweb/2A1.htm>. Accessed on May 1, 2000.

Pillard, D. A. 1996. "Assessment of Benthic Macroinvertebrate and Fish Communities in a Stream Receiving Runoff From a Large Airport." *Journal of Freshwater Ecology*. 11(1): 51-59.

Pillard, D.A. 1995. "Comparative toxicity of formulated glycol deicers and pure ethylene and propylene glycol to *Ceriodaphnia dubia* and *Pimephales promelas*." *Environmental Toxicology and Chemistry*. 14(2): 311-315.

PMC Specialties Group, Inc. 1996. COBRATEC TT-100 Technical Bulletin. Technical Report. Rocky River, OH.

PRO-ACT. Sept 1995. *Storm Water Pollution Prevention*. PRO-ACT Fact Sheet TI#6727.

Radiant Energy Corporation. Feb 1998. "Taxi-Thru Infrared Pre-Flight Deicing System." Available from: <http://www.rhiairport.com>. Accessed on: Jan 3, 2000.

Raja, L. M., Elamvaluthy, G. et al. 1991. "Novel Biotreatment Procedures for Glycol Waters." *Applied Biochemistry and Biotechnology*. 28/29: 827-841.

Rice, P. J., Anderson, T. A., Coats, J. R. 1999. "Evaluation of the Use of Vegetation for Reducing the Environmental Impact of Deicing Agents." *Phytoremediation of Soil and Water Contaminants*, Eds. E. L. Kruger, T. A. Anderson, J. R. Coats, ACS Press, Washington DC.

Risk Sciences and Management Group. Feb 1996. "Comparative Toxicity and Environmental Impacts of Ethylene Glycol and Propylene Glycol: A Review." EA Engineering, Science, and Technology, Inc. Silver Springs, MD.

Ryan, M.E., Peters, F.W., 2000. "Air Force Environmental Policy." Available from: <http://www.af.mil/environment/policy.html>. Accessed on: Jan 13, 2000.

Ruddick, J. A. 1972. "Toxicology, Metabolism, and Biochemistry of 1,2-Propanediol." *Toxicology and Applied Pharmacology*. 21(102-111).

- Sabeh, Y., Narasiah, K.S. 1992. "Degradation Rate of Aircraft Deicing Fluid in a Sequential Biological Reactor." *Wat. Sci. Tech.* 26(9), 2061-2064.
- Safferman, S.I., Siruvalure, G.S., Foppe, L.E. 1998. "Deicing Fluid Treatment in Batch-Loaded Aerobic Fluidized Bed Reactor." *Journal of Environmental Engineering*. 124(1), 11-15.
- Schroeder, E.D. 1977. *Water and Wastewater Treatment*. McGraw-Hill, Inc.
- Schulz, M., Comerton, L. J. 1974. "Effect of Aircraft Deicer on Airport Storm Runoff." *Journal WPCF*. 46(1): 173-180.
- Seele, T. March 2000. Radiant Technology Vice President. Personal Interview.
- Shieh, W.K., Lepore, J.A., Zandi, I. 1998. "Biological Fluidized Bed Treatment of Ethylene and Propylene Glycols." *Water Science Technology*, 38(9), 145-153.
- Shupack, Deborah P. 1997. "Influence of Vegetation on Mineralization of Propylene Glycol in Soil: Reducing Environmental Impact of Deicing Fluids in Water." M.S. Thesis, Clemson University.
- Sills, R.D., Blakeslee, P.A. 1991. "The Environmental Impact of Deicers in Airport Storm Water Runoff." *Chemical Deicers and the Environment*. Lewis Publishers, London. 323-340.
- Smith, D.W., Facey, R.M., Novotony, F., Kuemmel, D.A. 1996. "Management of Winter Diffuse Pollution From Urban Areas: Effect of Drainage and Deicing Operations." *Col Regions Impact on Civil Works*. Newcomb, D. Reston VA. 243-257.
- Speece, R.E. 1998. "Anaerobic Treatment of Airport Deicing Wastewaters." Seminar at Albany Airport, New York. January 18, 1998.
- Stephenson, R.L., Blackburn, J.B. 1998. *The Industrial Wastewater Systems Handbook*. Lewis Publishers, New York.
- Strong-Gunderson, J. M., Wheelis, S. et al. 1995. "Degradation of high concentrations of glycols, antifreeze, and deicing fluids." *Microbial processes for bioremediation*. R.E. Hinchee, R. J. Brockman and C. Vogel. Columbus, OH, Battelle Press. 3: 265-270.
- Sumwalt, R.L. Mar 1993. "Air Carrier Ground Icing." *ASRS Directline*. Available at: http://eos.arc.nasa.gov/ASRS/dl5_ixe.html. Accessed on Jan 24, 2000.

Transport-Canada. 1985. "State-of-the-Art Report of Aircraft Deicing/Anti-icing." Ottawa, Ontario, Canada, Ministry of the Environment, Professional and Technical Services, Facilities and Environment Management.

Tymco Regenerative Air Sweepers. May 2000. "Street Cleaning and Storm Water Quality." Available at: <http://www.tymco.com/quality.html>. Accessed on May 5, 2000.

United States Air Force/ CVA. Dec 1996. "Interim Guidance Pollution Prevention and Best Management Practices for Aircraft and Airfield Deicing/ Anti-icing Operations." CEVQ, Washington D.C.

U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. 1993. "Technical Report for Ethylene Glycol/Propylene Glycol." Report 205-88-0608. Washington, D.C.

U.S. Environmental Protection Agency. 1993. *NPDES Stormwater Program Question and Answer Document*. EPA-833/F-93-002B, Office of Water. Washington, D.C.

U.S. Environmental Protection Agency. 1993. *Storm Water Management for Industrial Activities: Pollution Prevention Plans and Best Management Practices*. EPA-959/F-93-043, Office Water Branch. Washington, D.C.

U.S. Environmental Protection Agency. 1994. *Addendum to Municipal Wastewater Management Fact Sheets Storm Water Management Practices*. EPA-832/F-93-013, Office Water Munic.Technol. Branch. Washington, D.C.

U.S. Environmental Protection Agency. 1995. *Emerging Technology Report: Preliminary Status Of Airplane Deicing Fluid Recovery Systems*. . EPA-832/B-95-005, Office Water Branch. Washington, D.C.

United States EPA. Oct 13 1998. "On-Site Recovery of Glycol from Airport Deicing Fluid Using Polymeric/Ceramic Composite Membranes." Final project Report US EPA Contract No 68d6058,

U.S. Environmental Protection Agency. 1999. *Storm Water Technology Fact Sheet: Airplane Deicing Fluid Recovery Systems*. EPA-832/F-99-043, Office Water Branch. Washington, D.C.

U.S. EPA. 1999. "Pollution Prevention/Environmental Impact Reduction Checklist for Airports." Office of Federal Activities. Available at: <http://www.epa.gov/oeca/ofa/pollprev/airport.html>. Accessed: Dec 27, 1999.

United States EPA. Sept 1999. "Stormwater Technology Fact Sheet: Flow Diversion." Office of Water, Washington D.C. EPA 832-F-99-014

United States EPA. Jan 2000. "Ethylene Glycol." United Air Toxics Office of Air Quality Planning and Standards. Available at: <http://www.epa.gov/ttnuatw1/hlthef/ethy-gly.html>. Accessed Jan 3, 2000.

Urbonas, B., Stahre, P. 1993. *Stormwater Best Management Practices and Detention for Water Quality, Drainage, and CSO Management*. Prentice-Hall, Inc. New Jersey.

Veltman, S.H. 1998. "Anaerobic Treatment of Aircraft Deicing Fluids: A Technology Assessment." Presentation at the University of Massachusetts, Amherst.

Veltman, S.H., Schoenberg, T., Switzenbaum, M.S. 1998. "Potential for Anaerobic Treatment of Airport Deicing Fluids." *Wat. Res. Env.* 33(4), 239-244.

Wanielista, M.P. 1979. *Stormwater Management Quantity and Quality*. Ann Arbor Science Publishers, Inc. MI.

Waste Streams Environmental Inc. January 2000. "Anaerobic: Coming of Age." MTF Mobilized Film Technology.

Westmark, C. March 7, 2000. "Environmentally Advantaged Substitutes for Ethylene Glycol Aircraft Ice Control." Foster-Miller, Inc. Brief on Self-Remediating Fluid Concept Feasibility to the Scientific Advisory Board. SERDP.

Williams, W. A. and R. J. 1997. "Low-Temperature Microbial Aerobic Degradation of Polychlorinated Biphenyls in Sediment." *Environ. Sci. Technol.* 31: 3491-3496.

Willems, Andrew. 1981. "Bacterial Metabolism of Ethylene Glycol." *Biochimica et Biophysica Acta*, 677:194-199.

Willems, Andrew. 1979. "Bacterial Metabolism of Propane-1,2-diol." *Biochimica et Biophysica Acta*, 588:302-309.

Wright Laboratory. 2000. "New Forced Air Deicing System Cuts Costs." Available at: http://www.wrs.af.mil/infores/ssstories/ss96/ss05_96.htm. Accessed Jan 18, 2000.

VITA

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This report was typed by the author and does not represent the views of the military.